8-2017

Landscape-Scale Geophysics at Tel Shimron, Jezreel Valley, Israel

Rachel Grap
East Tennessee State University

Landscape-Scale Geophysics at Tel Shimron, Jezreel Valley, Israel

---

A thesis

presented to

the faculty of the Department of Geosciences

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Science in Geosciences

---

by

Rachel M. Grap

August 2017

Eileen Ernenwein, Chair

Andrew Joyner

Adam E. Miglio

Keywords: archaeological geophysics, tels, ground-penetrating radar, magnetometry

ABSTRACT

Landscape-Scale Geophysics at Tel Shimron, Jezreel Valley, Israel

by

Rachel M. Grap

Ground-penetrating radar (GPR) and magnetometry were used at Tel Shimron, an archaeological site in Israel's Jezreel Valley. GPR primarily measures electric properties while magnetometry measures magnetic properties, making them complementary methods for subsurface prospection. Magnetometry can be collected and processed quickly, making it an ideal landscape-scale reconnaissance tool. It takes more time to collect, process, and interpret GPR data, but the result is a higher resolution dataset. In addition, GPR often works better than magnetometry in desert environments such as the Jezreel Valley. Conventional wisdom suggests that GPR should not be used as a landscape-scale reconnaissance tool unless there is ample time to process and interpret the data. Despite this, GPR was used at Tel Shimron with standardized, semi-automated processing routines and eight field technicians to produce an end product. The GPR survey revealed more about the subsurface than magnetometry, including three potential dwellings and a Bronze Age city gate.

ACKNOWLEDGEMENTS

I would like to thank my committee for their support and guidance throughout the project: Drs. Eileen G. Ernenwein, Andrew Joyner, and Adam Miglio. Eileen, thank you for introducing me to the wonderful world of archaeological geophyscs and for your support throughout the entire data collection and writing process. I cannot thank you enough for everything you have done for me over the past two years. Andrew, the past two years have been thoroughly enjoyable and fun. Because of you, I have had the opportunity to greatly improve my GIS skills and learn new software programs and analyses I had no idea existed before walking into the GEL. Adam, thank you for all of your support both during data collection and after. Your knowledge of and passion for archaeology in the Near East, which proved to be a valuable resource during this project, is both impressive and inspiring.

To Dr. Daniel Master of Wheaton College and Dr. Mario Martin of Tel Aviv University, thank you for allowing me to survey Tel Shimron for this thesis and especially for providing funding and leadership for the project. Thank you also to Dr. Matthew J. Adams and the W.F. Albright Institute of Archaeological Research's Jezreel Valley Regional Project for their support.

A very special thank you to my crew of volunteers for the geophysical survey. Without their tireless efforts, the massive amount of data wouldn't have been collected in such an efficient and timely manner. Much thanks to Cayla Cannon, Emily Holda, Abby VanderHart, Elise Laugier, Danielle Chiou, Na Hee Heo, Na Lim Heo, Zack Stubblefield, Everett Miglio, Graham Miglio, and Sarah Miglio. You all made the summer truly fun and memorable.

I would also like to thank the surrounding communities, especially Timrat, Ramat Yishay, and Nahalal, for their support of and interest in the archaeological work at Tel Shimron.

Many thanks to the faculty and graduate students of the GEOS department at ETSU.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND BACKGROUND

Introduction

Archaeological tel sites in Israel are typically excavated in one location tens of meters in depth over many field seasons. Because of this, the selection of a location to excavate is of great importance. Geophysical reconnaissance surveys provide geophysical data on the site prior to the disturbance caused by archaeological excavation, offering insight into the overall occupation and spatial layout of the site. Some sites have steep slopes and extensive modern structures or trash accumulation that may impact data quality. This limits the type of instrument that can be effectively used. Slope and rocky terrain make use of carts difficult and surface metal interferes with magnetic readings. Ground penetrating radar (GPR) should be used as a reconnaissance tool where it is likely to yield better results than other methods. This thesis offers a case study of Tel Shimron as evidence to this this claim.

Tel Shimron is a complex mound site in Israel's Jezreel Valley (Figure 1), an area characterized by steady human settlement and known as the region's "breadbasket" (Finkelstein 2006). Occupations on the tel range from the Neolithic period to a 20th century refugee camp, with significant level of occupation during the Middle to Late Bronze Age, Iron Age I-II, Byzantine, and the Mamluk periods (Portugali 1982). The tel is approximately 60 meters taller than its surroundings, making it the largest tel in the Jezreel Valley.

Figure 1. Location of Tel Shimron within Israel and the broader Levant region.

Portugali (1982) conducted a systematic pedestrian survey to assess the occupational history of Tel Shimron, but the site has never been excavated. With excavations set to begin summer 2017, only one six-week field season in summer 2016 was available for a geophysical survey that could be used to inform excavation planning. Unlike most archaeological sites in other parts of the world, tel sites require excavation in the same location for many field seasons, thus making excavation planning an expensive decision and, therefore, necessarily targeted. Once an area is opened for excavation, it will likely remain open for numerous years, while most portions of the site may never be excavated. This allows for eventual excavation of older, deeper deposits.

The 19.5-hectare tel has steep slopes, basalt quarries, partial tree-cover, dozens of concrete slabs left over from a historic Jewish settlement, and modern trash piles in several locations. Use of large carts and GNSS-integration was ruled out because of the steep slopes, tree cover, and other obstacles. Magnetometry and EMI would be limited because of abundant metal trash on the surface, exposed basalt quarries flanking the tel, and basalt cobbles strewn about the surface. It was determined that GPR with a single antenna would be the best geophysical approach. Magnetometry with a dual-sensor was also utilized simply because it adds very little extra time once grids are set up for GPR survey. To survey as much of the tel as possible within the short field season, a crew of 8 people surveyed the site over the course of five weeks, and processed the data on site in real-time.

Archaeological Geophysics

Geophysics has been used in archaeology since the 1930s. The first known geophysical survey in North America for archaeological purposes was in 1938 at Colonial Williamsburg where an equipotential survey was conducted in an attempt to locate an early historic feature (Bevan 2000). The magnetometer became widely used in archaeology in the early 1950s in Great Britain (Walker 2009). Pulse ground penetrating radar was patented in 1926, though it was first used for geologic surveys. In Israel, it was first applied to archaeology in 1981 to examine ancient structures in the Old City of Jerusalem (Dolphin 1981, Epplebaum 2010). Today, archaeological geophysics is widely used in Europe and is gaining favor in the US and elsewhere (Kvamme 2003)

Field methods for archaeogeophysics surveys use a system of grids and closely spaced transects. For instance, a 30 by 30 meter grid with two transects evenly spaced for every meter, collected in a zig- zag or parallel pattern is typical. Exact grid size, transect spacing, and collection pattern depend heavily on site size and terrain. As GPS-enabled systems become more readily available, data collection with larger, cart-based instruments is becoming more popular and in some cases, the grid system may not be used. This offers the benefit of faster data collection and larger areas. However, not every archaeological site is ideal for these systems, as the carts tend to require a relatively flat and open space. As such, grid-based, single-sensor surveys are still required at many sites.

Magnetometry

Magnetometry measures magnetic susceptibility and remanent magnetism of Earth's near surface sediments (Kvamme 2003). The Earth's natural magnetic field occurs due to the dense iron core at the center of the planet and is measured in nano-Teslas (nT). Solar activity, iron content in sediment, as well as the smaller-scale effects of anthropogenic activity, can influence the Earth's magnetic field locally (Gerard-Little et al. 2012). Archaeological features that contain ferromagnetic materials, such as iron, as well as burned features like hearths and roasting pits show up as strong anomalies in the data (Kvamme 2003). The magnetometer typically "sees" archaeological features up to about 1.5 meters below the surface, though a large metal object, such as a car, could be seen at a greater depth. However, historic and geologic features can cause a stronger anomaly in the magnetometry data, which may obscure prehistoric features.

Magnetometry for Archaeology

Magnetometry is a highly applicable tool for archaeology for several reasons. People create fired artifacts and use iron and stone materials, which show up clearly in the data (Kvamme 2003). Additionally, constructions by people remove topsoil, which is highly magnetic due to presence of magnetotactic bacteria. This change in soil location is reflected in the data because magnetic topsoil will be present in significant amounts in places other than just the surface level (Kvamme 2003). There is also a high likelihood that features may be burned, either due to intentional burning or regular use, which results in strong magnetic anomalies. Remnants of metallurgy, or metal working for creation of tools or weapons, will cause an anomaly in the data as well. Historic archaeological features usually change the magnetic readings by approximately 100 nT, while prehistoric archaeological features tend to cause a change on the order of 10 nT (Kvamme 2003). Benefits of magnetometry for archaeology are that data collection and processing are relatively fast and easy and that the magnetometer is very sensitive to subtle differences in the magnetic field particularly due to human modification of the landscape (Kvamme 2003).

Magnetometry has commonly been used for archaeology since the 1950s to detect archaeological features (Anthony 1996). A proven method for analyzing Woodland and Mississippian sites in the United States, magnetometry has been used at Iroquois sites in New York (Gerard-Little et al 2012), located burned Menoken Villages in North Dakota (Kvamme 2003) and identified a central hearth at Whistling Elk Village (Kvamme 2003). Late Bronze Age sites in Greece have been well documented through magnetometric prospection and the Archaeological Reconnaissance of Uninvestigated Remains of Agriculture (AROURA) (Lane et al. 2016), and Mesolithic structures were identified using magnetometry in northern Spain (Arias et al. 2015). In Israel, magnetometry has been used to map magmatic occurrences in the Central Arava (Hanan et al. 2014). For archaeology, it was used to study the submerged harbor at Caesarea Maritima, where magnetic anomalies indicated there was a concrete foundation to form two artificial islands. Low points of magnetic susceptibility also identified baffles used to stabilize the structure (Boyce et al. 2004).

Instrumentation

When considering a magnetometry survey, Kvamme (2003) discusses three types of magnetometers: proton precession, cesium vapor, and fluxgate. While fluxgate is the most commonly used in archaeology, cesium vapor magnetometers are also proficient. The proton precession, however, is a much slower technology typically used for geologic purposes (Kvamme 2003). There are several magnetometer configurations available for use, particularly total field, base-rover, and gradiometer (Bruseth et al. 2007), all of which have been used for archaeology. A gradiometer uses two magnetometers and can subtract the earth's magnetic field from the data by identifying the frequency and magnitude at which the magnetic field is occurring and zeroing it out (Witten 2006). Some magnetometers are carried by the researcher while others can be attached to a cart and pushed by the researcher or pulled by a car (Bruseth et al. 2007). Their frame is made from a non-ferrous material such as carbon fiber so as not to interfere with the readings.

Field Methods

It is important for data collection that the researcher collecting the data wear no ferrous metal, including undergarments and shoes, as well as ensuring keys and cell phones are not on their person. Additionally, metal trash and deposits on the site surface should be removed prior to data collection, as these will interfere with the readings. Such debris, along with metal poles, signs, and other structures may also cause the data to be "blown out", or obscure the subtler archaeological features (Kvamme 2003).

The magnetometer is first tuned to determine the Earth's magnetic field at the site so that the subtle changes in magnetic readings across the sites can be passively identified by the instrument (Johnson 2006). This is done by collecting readings with the gradiometers facing each cardinal direction and then inverting the magnetometer for additional readings. The signal is calculated automatically and zeroed out. Data are collected along a grid with the researcher carrying the magnetometer and walking at a specified pace to ensure even sampling (Clark 1996). It can be collected in a zig-zag pattern or all in one direction. The Grad601 (Bartington,UK), a dual-sensor fluxgate magnetometer (Figure 2), allows the user to specify which collection method is being used.

Figure 2. A Grad601-2 dual-sensor magnetometer was the instrument used for this survey.

Data Processing

Data are downloaded and can be processed in software such as Archaeofusion or Terrset to remove striping or staggering that may have occurred during data collection. Transect striping may be present in the data because the two sensors that have been tuned independently of one another and thus have two different zero points. Such striping is removed from the blocks by de-striping or balancing differences between the detectors using Zero Mean Traverse, a method that subtracts the mean of each traverse from all samples in that traverse (Johnston et al. 2006). Staggering in the data occurs when the researcher collecting the data in the field walks too fast or too slow for the pace set per meter and causes the data to look as though rows or columns have been shifted in one direction. The staggering is rectified by shifting the individual rows or columns of data based on the degree to which staggering occurs (Johnston et al. 2006). Plow marks are often present in archaeological data, but can be removed during processing using Fourier analysis, a method that isolates and concentrates narrowband signals making them easier to remove (Johnston et al. 2006).

Ground Penetrating Radar

Theory of Operation

Ground penetrating radar (GPR) is a non-invasive geophysical method that sends pulses of radio waves into the ground and records reflections off of subsurface entities including archaeological features (Conyers and Goodman 1997). It has become a popular non-destructive method for locating buried objects. GPR consists of transmitter and receiver antennas that are pulled along the ground surface in transects, and are connected to a data collector typically worn in a harness by the user. The antenna sends radio waves into the ground and records their reflections, or "echoes," off of buried objects (Conyers 2006). Specifically, the transmitter generates short bursts of electromagnetic energy and sends them into the ground, where they travel at a velocity dependent on the dielectric constant of the sediment being transmitted through (Conyers and Goodman 1997). Dielectric permittivity refers to the ability of a material to become polarized by the radio waves (Conyers and Goodman 1997). The strength of each reflection and the time elapsed is used to reconstruct the depth and general size of buried features and objects (Conyers and Goodman 1997). As the radio wave encounters a change in sediment type, a portion of the wave is reflected back to the ground surface. This reflection is recorded by the receiver antenna. The time lapse between the transmission and reception of the radio wave is determined by velocity and distance traveled from the transmitter to an interface and finally to the receiver. This information is then used to create a graphic reconstruction (Conyers and Goodman 1997).

The GPR creates two main types of reflections that appear in the raw data: hyperbolas and planar reflections. Hyperbolas occur from a point source and look like an inverted "U." Planar reflections are linear reflections that typically show a change in velocity in the ground due to a change in chemical composition or grain size (Conyers and Goodman 1997).

The frequency of the antenna and the soil dielectric determine the depth that the radio waves can reach. The lower the frequency, the deeper the radio waves can travel beneath the surface. However, as frequency decreases, so does the resolution quality; a high frequency antenna may not be able to ‘see’ as deep into the earth as a lower frequency one, but it will be able to resolve smaller features under the ground (Conyers, 2006). One major concern with GPR is background noise. Cell phone and radio noise can show up in and interfere with the data, but so can power lines, radio stations, and underground telephone lines which may be within or near the survey area. They can dominate the signal to the point that features cannot be resolved (Goodman and Piro 2013).

Another concern with GPR is attenuation. Attenuation is the loss of intensity in signal over time as it encounters certain materials, sediments or circumstances (Conyers and Goodman 1997). Water on the surface as well as pooling underground can cause attenuation. Other materials, such as concrete, also cause attenuation of the signal. Additionally, certain sediments, such as clay, are said to be “lossy” and will also cause attenuation (Conyers and Goodman 1997).

GPR for Archaeology

As the method is non-invasive, GPR is ideal for archaeology in that it allows for the studying of an archaeological site without ever breaking ground prior to ground-truthing, keeping the site intact and undisturbed. GPR allows for the study of geospatial data across a site as well as stratigraphically. This makes it possible to see archaeological features in time, an important asset to archaeological surveys as it provides information on the depth of these features.

GPR can sometimes give the spatial layout of the site as a whole, something that can rarely be accomplished with traditional archaeological methods. This geospatial analysis allows archaeologists to see the orientation of the site and aids in determining if there are multiple occupation periods. It can also provide archaeologists with a map of some of the features at the site they are excavating. By locating buried features prior to excavations, archaeologists know where to put in excavation test pits and trenches, saving time and resources.

Instrumentation and Field Methods

The GPR generally consists of an antenna, control unit, survey wheel, and/or a GPR receiver (Figure 3). Antennas may range from 80 to 1500 MHz, though most archaeological sites will be surveyed best with 270-500 MHz (Conyers and Goodman 1997). The antenna can be monostatic, meaning the radar transmitter and receiver are in the same casing, or bistatic, where the radar transmitter and receiver are in separate casings and the receiver follows behind the transmitter. There are several options for GPR configuration. The first is a separate base station and roving antenna. Another option is carrying the control unit while dragging the antenna. More still are the most recent configurations; the GPR system can be mounted on a cart and towed behind a vehicle. The first two methods work well for grid surveys, while the last is typically used in landscape scale, reconnaissance surveys. Data are collected in transects within grids, which provides data in the form of radargrams, or reflection profiles.

Figure 3. A GSSI SIR-4000 GPR system with a 400 MHz antenna and survey wheel, similar to the system with a 270 MHz antenna used for this project.

Data Processing

GPR data can be processed using various data processing software, such as GPR-Slice or Radan. The ability to slice in time or depth allows the data to be viewed stratigraphically, providing the opportunity to see whether multiple occupations are present at the site. Radargrams visualize the data in a way that hyperbolas and planar reflections can be viewed. This is important because different features cause different types of reflections. Sometimes the type of reflection can be interpreted as a specific archaeological feature.

Filtering is an important part of processing GPR data. According to Goodman and Piro (2013) bandpass, background filter, and Hilbert transform are all common algorithmic filters than can be used to help extract and identify features in the data that may be obscured by background noise. Bandpass filtering allows signals between two specified frequencies to pass, but removes all other frequencies. The background filter removes relatively constant background noise so that the feature signals will be more evident in the data (Goodman and Piro 2013). A smoothing of the waveform is done by the Hilbert transform. This shows the "envelope" of the radar pulses that is completely positive (Goodman and Piro 2013). Additional data processing solutions specific to this project to reduce noise in data and background noise field mitigation methods will be described later in this paper.

Tel Shimron

What is a Tel?

A tel is a complex archaeological mound site that has been occupied by multiple civilizations over time with each civilization building upon the remains of the previous civilization (Faust et al. 2015). Occupations may overlap horizontally, vertically, or both, but always instantiate a complex depositional process of human occupation over long stretches of time. Excavations of a tel seek to investigate buried structures such as government buildings, military encampments, religious centers, and homes. Archaeological geophysics provide a method for studying tels without causing damage to the features or the structure as a whole in addition to offering an opportunity to understand portions of the tel that excavations are prohibited from exploring due to time and resource constraints.

Tels in the Study Region

Tels in the Jezreel Valley hold a wealth of information and history. Tel Megiddo lies to the southwest of Tel Shimron and has been under excavation since 1903 (Finkelstein et al 2006). The discovery of an Early and Middle Bronze Age altar sheds light on the religious significance the tel once held (Illan 1991). With excavations exploring both the Iron Age and Bronze Age gates in addition to numerous dwellings and government buildings, Megiddo is one of the most extensively studied Jezreel Valley tels (Finkelstein et al 2006). Tel Jezreel acted as a sentry controlling its junction with the mountain route that leads to Samaria from Galilee (Ebeling and Franklin 2016). Similarly, tels in the northern region of Israel are connected through a congruent morphology and occupation periods (Albright 1925). Tel Dor on the Mediterranean coast near present day Haifa boasts an impressive sea wall that once provided the city protection from storm surge and sea winds (Gilboa and Sharon 2008). The location of Tel Dor is of particular importance as it provided a midpoint stopover for the Journey between Philistia and Phoenicia (Gilboa and Sharon 2008). Tel Dan, now a national park, is the site of an incredibly well preserved mud brick Middle Bronze Age gate leading into a once thriving city and religious site (Frances 2013). Tel Dan is also the site of an Israelite cultic precinct (Illan 1991). This interconnected story yields insight into the history and the archaeology of the region, and provides a framework for research at Tel Shimron.

Tel Shimron

Tel-Shimron lies on the northwestern edge of the Jezreel Valley, a major East-West valley in the Levant. The tel is approximately 60 meters taller than its surroundings (Figure 4). Shimron was a prominent fortified Bronze Age Canaanite city, as illustrated in the Amarna letters (Raban 1982). Hebrew biblical accounts identify the Shimron site as one of cities attacked by Joshua and defeated by the Israelites, which is supported by the likely restriction of the Iron Age occupation of the tel (Raban 1982). The village present at Tel Shimron, called Simonia, during the Roman Period likely benefited from traffic on the Legio-Sepphoris road (Strange 2014). These are just a few of the civilizations to have been present at Tel-Shimron. Through the geophysical survey of the site, the intricate past of Tel Shimron and the role it has played in the history of many peoples will be better explored and understood.

Figure 4. Tel Shimron, seen here from the center of the tel looking east towards the acropolis, is steeply sloped.

The Jezreel Valley is rich in archaeological sites and extensive history, having been occupied since the Neolithic period (8500 - 4300 BCE), a time of agricultural transition and development of farming economies in the Near East. As the Neolithic became the Chalcolithic (4300 to 3330 BCE), extensive trade networks throughout the Levant brought foreign goods and people to the Jezreel Valley, as well as an emergence of vine and olive horticulture, which would continue to thrive in the region to the modern day (Covello-Paran 2015). Urban development increased with the Early Bronze Age and continued through the Middle Bronze Age (2000 - 1550 BCE) , when Amorite and Akkadian Kingdom influences were spread across the Near East, including the Jezreel Valley (Covello-Paran 2015). The Late Bronze Age (1550 BCE - 1200 BCE) is characterized by a strong Egyptian-Hyksos influence, up until the empire’s fall, signaling the start of the Iron Age-Israelite Period (1220 BCE- 539 BCE) (Killebrew 2005).

City-States and small kingdoms were what remained in the Levant during the Iron Age, though several Phoenician ports remained and became significant commercial centers (Gal 1992). Israelites, in an effort to escape the Bronze Age collapse throughout the Levant, built rural communities in Judea. Technological innovations emerged, perhaps most notably the process of iron working. The Persian Empire exerted its control over the Levant during the Persian Period (539-332 BCE) and Zoroastrianism was introduced across the empire. Alexander the Great conquered the Levant in 332 BCE, signaling the start of the Hellenistic Period (332 - 63 BCE). The Hellenistic period in the Levant experienced innovation in math, science, and architecture. The Herodian period was one of most notable subperiods of the Early Roman period (63 BCE-70 CE), experiencing unprecedented construction, such as Masada to the south of the Jezreel and the prominent port of Caesarea to the west. The Middle Roman period (70 -135 CE) is characterized by conflict, specifically the Jewish-Roman Wars (Josephus, Wars of the Jews). The Late Roman Period (200-330 CE) saw the decline of Rome and the loss of the Levant to the Byzantine period (330-634 CE).

The Byzantine Empire conducted a series of crusades to "spread Christianity" and extend the empire into the Levant, and as a result, many churches were built in the Near East (Sharfstein 1994). The Byzantine-Sasanian War exhausted the empire's resources and eventually led to the loss of the Levant territory to the Sasanians (Sharfstein 1994). The Sassanid Empire in present-day Israel or *prima palestina* (611-638 CE) was conquered by the Islamic Caliphates (638-1099 CE), and Islam replaced Christianity as the dominant religion of region. The Rashidun caliphate, whose capital was in Medinah, was the first to rule prima palestina. They were followed by the Damascus based Umayyad caliphate and then later by the Baghdad-based Abbasid caliphate. A crusader state at Acre, to the west of the Jezreel Valley, survived the Ayyubid conquest, though the rest of the former Kingdom fell to Ayyubid rule (Sharfstein 1994). The Jezreel Valley and the rest of present-day Israel saw fighting between the crusaders, Mongol invaders, and Mamluks from Egypt from 1260 to 1291, when Sultan Qutuz defeated the Mongols and his successor

Sultan Baibars defeated the crusader Kingdom of Acre bringing Mamluk rule to the region (Scharfstein 1994). The Ottoman Empire conquered the region in 1516 and it remained under Turkish rule until 1920 when it was divided between Britain and France under a mandate system and called Mandatory Palestine. An increase in the Jewish population during this time period was due to Zionism. Conflicts between Jews, the British government, and the Arab population ensued through 1948, when the State of Israel was formed (Marom 2014).

Previous analysis and excavations have been conducted on other tels in Israel, though little other than surface collections has been done on Tel- Shimron (אחיטוב and Ahituv 1981, Jezreel Valley Research Project 2015, Portugali 1982). This thesis seeks to determine the spatial layout and orientation of the various civilizations through GPR slices of occupation layers at Tel-Shimron and types of land use and occupation by these civilizations. Additionally, Tel-Shimron will be used to identify efficient ways to conduct landscape-scale geophysical surveys and up-to-date data processing in real time. Lastly, the survey will identify areas of potential trench locations and targeted excavations to be carried out by Daniel Master, Ph. D of Wheaton College and Mario Martin, Ph. D of Tel Aviv University in summer 2017.

Use of geophysics at Middle Eastern sites

GPR has been used in the Middle East for the exploration of archaeological sites. Casana et al. (2008) explored Tell Qarqur in Syria using GPR and electrical resistivity. Several Early Bronze Age and Iron Age structures were located that offered insight on the settlement and organization layout of Tell Qarqur. Novo et al. (2014) conducted a GPR survey on Tell Qubr Abu al'Atiq in Syria with the goal of locating an Early Bronze Age occupation on the lower end of the tell, which was found to have been a circular, walled city. Conyers et al. (2002) surveyed the "Lower Market" at the city center east of the Great Temple in Petra, Jordan, finding several structures, including one that was a rectangular outline with an open center.

Despite its usefulness, GPR has been applied infrequently at archaeological tel sites in Israel. Its most common use by Israelis is to locate and recover unexploded mines (Eppelbaum 2010). GPR was used to investigate near surface occupations at Marj Rabba, a Chalcolithic site in the lower Galilee (Urban et al 2014). The GPR survey of Tel Shimron contributes to the knowledge of archaeological geophysics on tels by illustrating how the instrument can be used specifically as a landscape-scale reconnaissance tool. By surveying a large area and encompassing much of the tel, not only can features be identified but the spatial patterns of occupations on the tel itself can be investigated.

CHAPTER 2

METHODS

Magnetometry and GPR are complementary geophysical methods. While GPR primarily measures electrical properties, it's response to magnetic permeability is so limited that it is irrelevant for most archaeological sites (Conyers and Goodman 1997). Conversely, magnetometry measures magnetic, but not electrical properties. Use of these two methods in concert can greatly increase the likelihood of identifying archaeological features and understanding them. Even though GPR was predicted to be the best method for Tel Shimron, it was logical to also include magnetometry since it added very little time and effort, and could potentially increase the success of the project.

Field Methods

GPR data were collected using a GSSI SIR-4000 system with a 270 MHz antenna and survey wheel attachment. Magnetometry data were collected with a Bartington Grad601-2 dual sensor fluxgate magnetometer. A matrix of 30 x 30 m grids was drawn over the entire surface of the tel, based on a one meter LiDAR-derived digital elevation model (DEM). Grids were rated high, medium and low priority for geophysical survey based on local slope values and the density and type of surface obstructions. All data were collected in the 30 by 30 m grids with transects spaced 50 cm apart. Because of the limited available time, areas were prioritized as high and low priority with the high priority areas being surveyed first. These included the acropolis of the tel at the eastern end, the lower western end, and the margins. The central part of the tel was given lowest priority due to the presence of many large cement platforms, which blocked smooth passage of the GPR antenna due to their height (40 cm, on average), and contained steel reinforcement bars that could obscure any features below them. Additionally, this area was also covered in thick, spiny thorns up to 90 cm tall, which made data collection painful. The coordinates of architecture visible from the surface were recorded for later comparison to data and a photo was taken of each grid from the southwest corner looking northeast. Overall, six hectares of GPR and nine hectares of magnetometry data were collected (Figure 5).

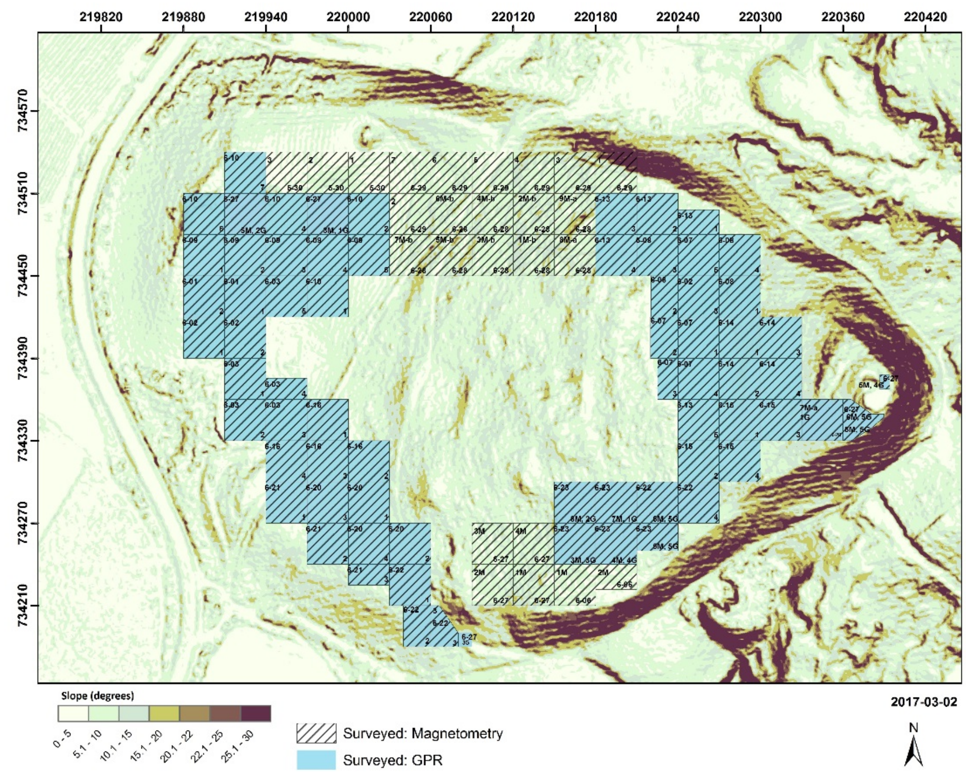

Figure 5. Location of the six-ha GPR and 9-ha magnetometry surveys at Tel Shimron.

All crew members arrived at site every morning at 5 am and began setting up the first grid, and then worked together in the field until 9 am to collect data on as many grids as possible during the coolest part of the day. Typically, three grids were collected with both magnetometry and GPR data during this early morning session. After morning field work, half the team focused on data collection while the other half processed data in the on-site mobile computer lab until noon when the two teams would switch. This allowed the teams to be productive for the entire day without being physically exhausted or exposed to heat for extended periods of time. It also ensured that data processing kept pace with acquisition and that the quality of data could be assessed quickly. Additionally, real-time processing provided preliminary results that were shared with local residents on community education day.

Data Processing

A workflow for GPR data processing was developed by the authors the first week on site to provide the rest of the team with step-by-step instructions to ensure that identical processing methods were implemented between crew members. Individuals had to check and sometimes modify automatically-generated gain curves, a range that allows for the amplification of the signal at specified depths, and select hyperbolic reflections, or the graphic reconstruction when the radar signal has reflected off an object, for velocity analysis. Otherwise, data processing was consistent from one crew member to the next. Steps to the workflow are illustrated in Figure 6 and Table 1 summarizes filters used in the data processing workflow. Data from the magnetometer required a considerably less involved processing workflow. Magnetometry data were clipped, standardized, destaggered and then destriped. Each method of processing is described in Table 2.

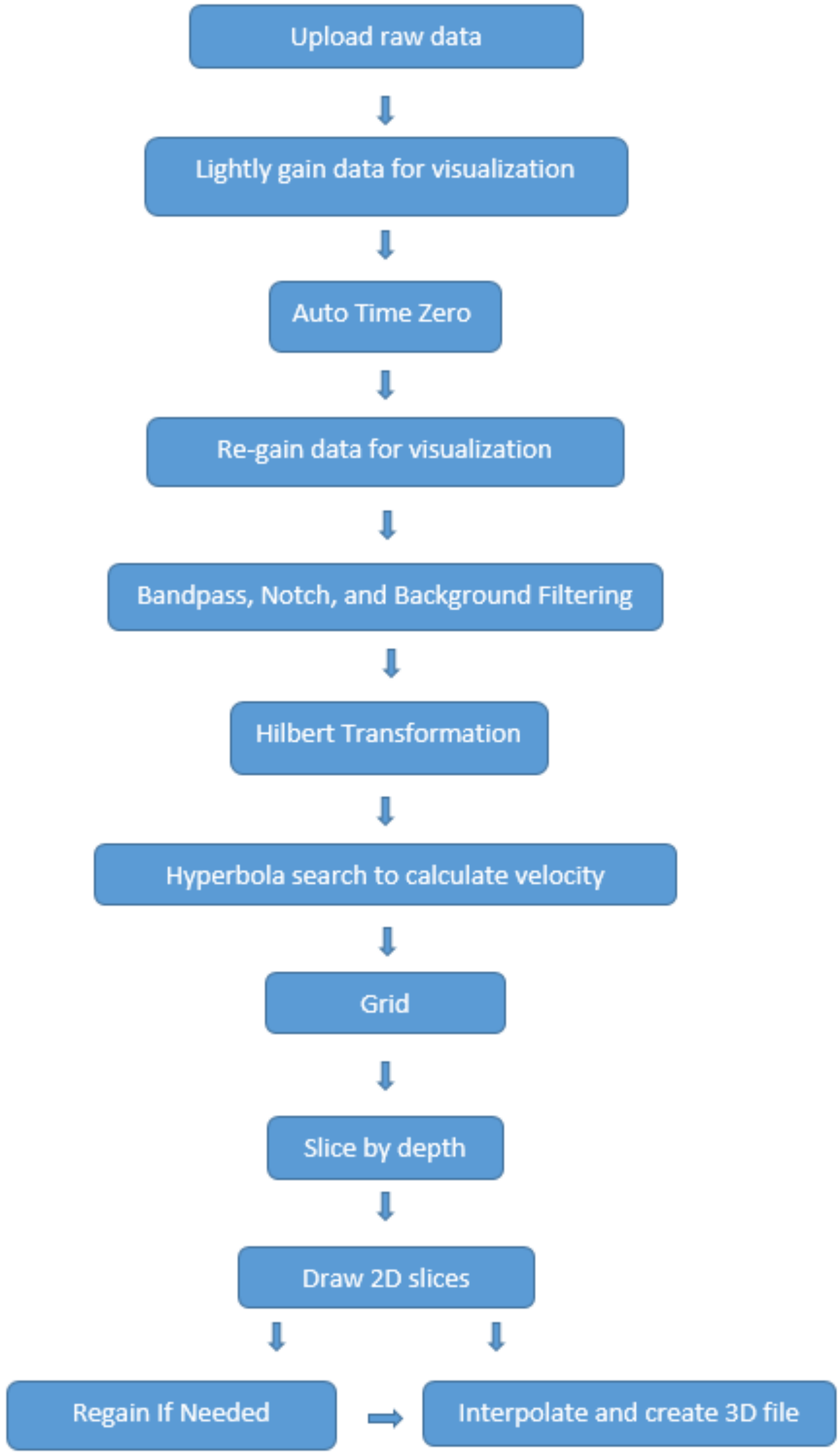

Figure 6. This workflow describes the steps used to process all GPR data at Tel Shimron.

Table 1: Explanations of each GPR data processing step used for the Tel Shimron data.

Data Processing Step	Description
Gain	Gaining amplifies the signal so that the user can visualize the data. Lightly gaining only slightly amplifies the data so that noise doesn't dominate the radargram and slices (GPR-Slice V7.0 User's Manual).
Auto Time Zero	A computer calculated truncation of the radargram at the point the signal enters the ground (0ns) removes all recorded information prior to 0ns (GPR-Slice V7.0 User's Manual).
Bandpass and Notch Filter	Bandpass allows signals between two specified frequencies, in this case 150 and 600 MHz, to pass, but removes all other frequencies. The notch filter allows a selected frequency, such as 190 MHz, to be removed even if it falls within the bandpass frequencies (Goodman and Piro 2009).
Background Removal	The background filter removes background noise by determining the average pulse across the radargram and subtracting that from each individual pulse in the data (Goodman and Piro 2009).
Hilbert Transform	This method calculates the "envelope" of radar pulses, resulting in only positive values (Goodman and Piro 2009).
Hyperbola Search	Velocity is calculated by the software by locating hyperbolas and recording their radius (GPR-Slice V7.0 User's Manual).
Grid	The sparse XYZ time slices are used to create a more dense .grd file using "standard geospatial interpolation routines," (GPR-Slice V7.0 User's Manual).
Slice	Radargrams are aligned in the grid and sliced by a user-specified time-depth (GPR-Slice V7.0 User's Manual).
Draw 2D Slices	Time slices created in the previous step are draw for visualization. Slices are planar views of the data at a specified time-depth (GPR-Slice V7.0 User's Manual)
Create 3D Time Slices	The 2D time slices are interpolated to create a 3D version for additional viewing and analyzing.

Table 2: Processing techniques for magnetometry data.

Processing Technique	
Clip	During data collection, scans were occasionally collected beyond the set parameters of the grid. Clipping removes any unintended scans.
Standardize	High and low readings were interpolated to be made uniform across the grids.
Destagger	Staggering occurs when the researcher walks too fast or too slow instead of a pace of 1 meter per mark. Destaggering rectifies this by shifting the transects.
Destripe	Minimizes striping patterns along the traverse direction by subtracting the traverse mean from each measurement in that traverse.

CHAPTER 3

RESULTS

Six hectares of GPR (Figure 7) and nine hectares of magnetometry data (Figure 8) were collected and processed in the field. All high priority areas were collected within the first week and a half of data collection, allowing the team to collect a significant portion of the lower priority areas with both GPR and magnetometry. Additional areas were surveyed with the magnetometer while waiting for the GPR survey to proceed. Only the centermost portion of the tel was not surveyed. Significantly more data were collected and processed during the allotted time than originally anticipated suggesting that the field methods used worked well for this type of survey.

Data interpretation allows a researcher to study and understand the data collected during a geophysical survey. When looking for areas of interest and potential archaeological features, start with locating geometric shapes. Right angles, circles, and rectangular anomalies are typical indicators of possible archaeological features. Depth, strength, and size are key to determining if an anomaly is an archaeological feature instead of noise or a geologic feature. Strong anomalies at the deepest point below the ground surface the radar is recording is typically noise. Features from the most recent occupation at Tel Shimron occur close to the ground surface, with earlier occupations occurring below those.

Slice mosaics show the entire site at one time-depth interval. Figure 7 shows ground-penetrating radar data at 30-40 cm below the ground surface. This depth was selected as it is close enough to the surface to catch the most recent occupation while still being deep enough to limit surface architecture impact. However, some surface architecture is visible at any depth as it creates a “shadow” effect; the signal cannot pass through it so nothing below can be recorded.

An example of this are the rectangular features on the south-central portion of the tel. These anomalies are the “shadow” of the concrete platforms on the surface of the tel. Additional anomalies that are present at this depth but are not archaeological features are plow marks, which can be seen in the northwest corner of the data collection area. There are also several long, sinuous anomalies at various locations on the tel. These correspond with pedestrian paths on the tel’s surface. All of the anomalies described are drawn in black, signaling a strong reflection. Both archaeological features as well as these modern features are depicted in black, making data interpretation an essential skill for geophysical surveys. The central area of the tel, which held more concrete pads, could not be surveyed due to the presence of thick bushes and thorns, which made it impossible to cover with the wheel based instrument and painful for the instrument operator. Despite these circumstances, there are several areas of archaeological interest in the data.

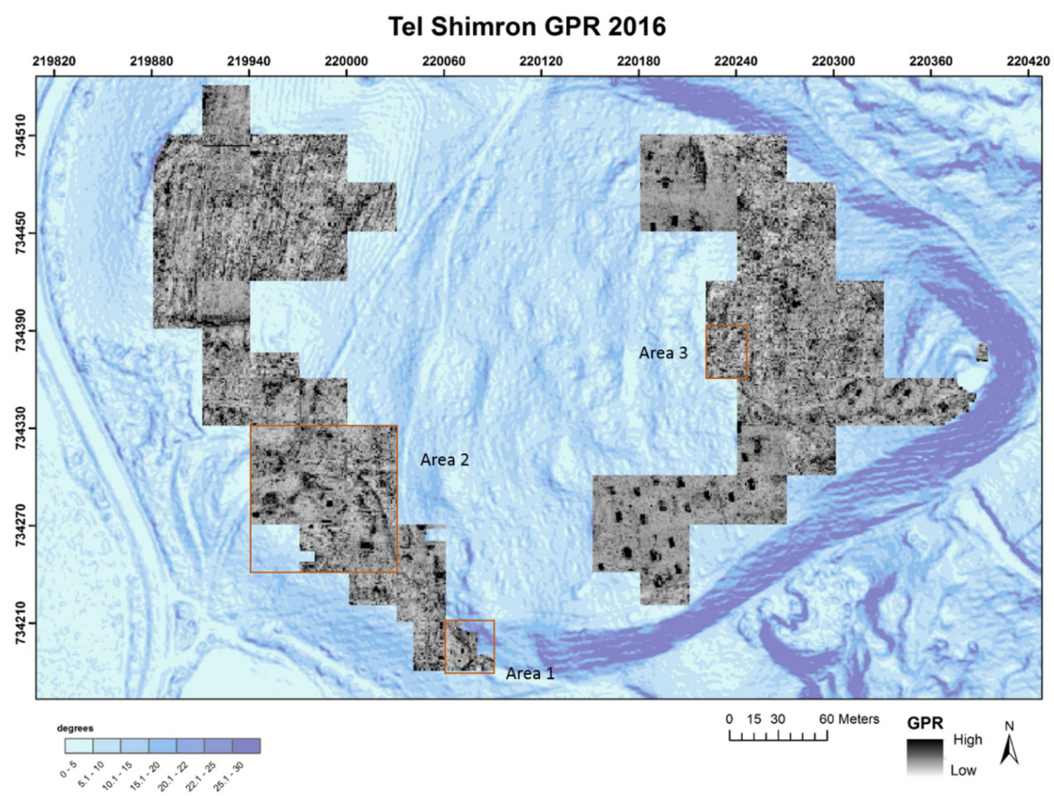

Figure 7. Site-wide GPR depth slice mosaic of 30-40 cm below the ground surface.

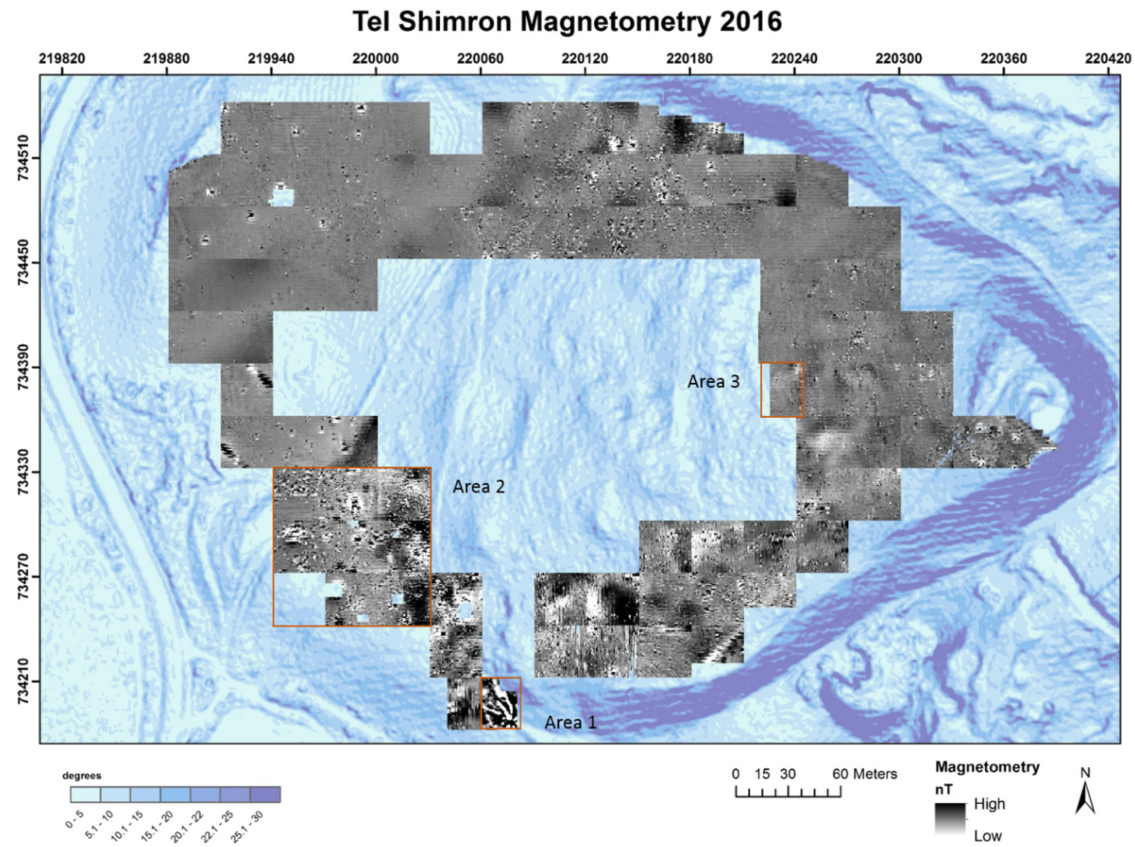

Figure 8. Nine ha of magnetometry data collected across the study site**.**

Areas of Interest

Area 1

Area 1 is located on the southwest of the tel. Here, strong reflections appear in both the magnetometry and ground penetrating radar (Figure 9). In the magnetometry, an area of roughly 20 x 20 meters is characterized by strong high and low readings, causing the data to have thick corridors of both black and white. This area appears "blown out". The ground penetrating radar in area 1 corresponds with the magnetometry data, showing right angles and interlocking lines at the same location as the "blown out" magnetometry feature. The anomaly begins to appear at 0.13 m below the surface and is a series of lines of varying lengths forming right angles.

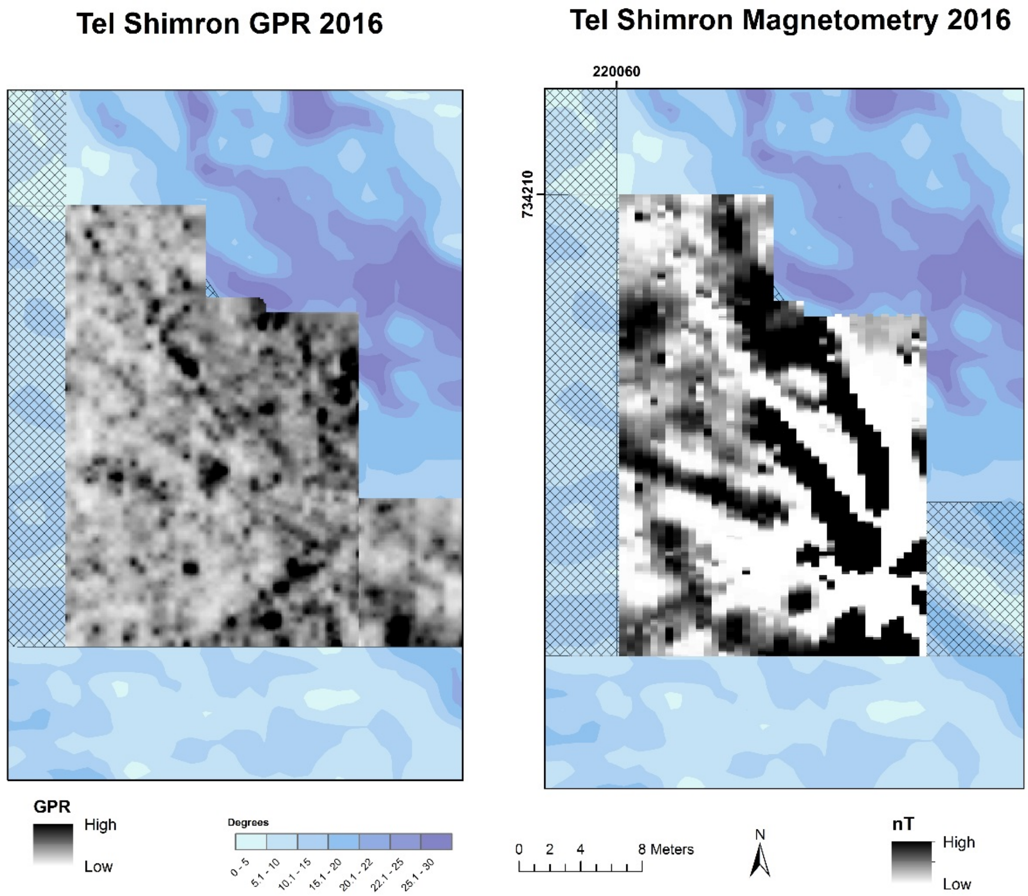

Figure 9. GPR (left) and magnetometry (right) of Area 1 on Tel Shimron. For GPR, anomalies of interest have high readings and are illustrated in black. Magnetometry data in this area has both maximum high (black) and maximum low (white).

Area 2

Area 2 is located on the southwest of the tel and 140 m northwest of Area 1. Here a series of linear reflections and circular anomalies are of particular interest (Figure 10). The reflections begin approximately 0.34 m below the ground surface and extend to a depth of approximately 0.88 m (Figure 11). The anomalies all appear in the data as a series of closely-spaced hyperbolas. Circular anomalies appear to be within the squares and rectangles made up of lines meeting at right angles. The sizes of the rectangles and squares formed vary, with the largest being approximately 28.3 m across and the smallest being only 4.52 m across.

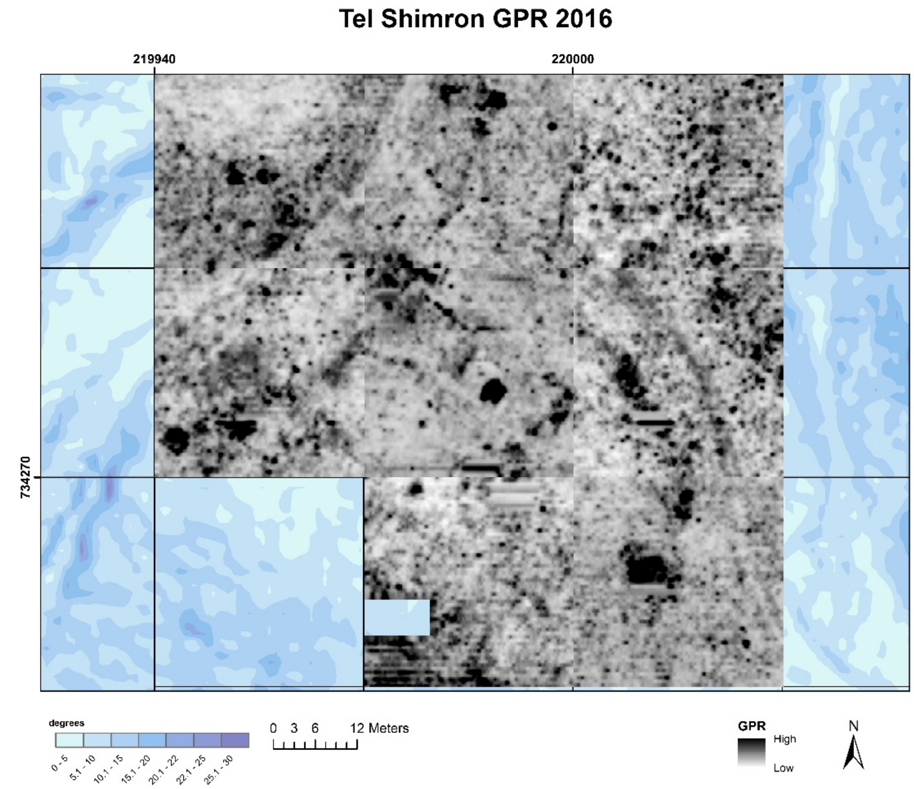

Figure 10. GPR data of Area 2. Reflections of interest are high readings, shown in black. A series of right angles, rectangles, squares, and circles can be seen in the slice of the tel at 52 cm below surface. In particular, there is a rectangular feature in the center of the area shown with interior partitions and an interior circular anomaly.

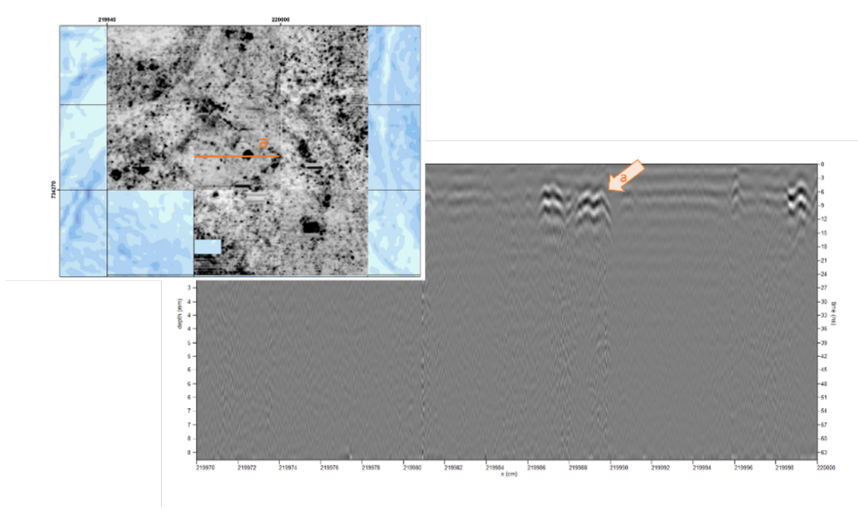

Figure 11. Circular potential feature (a) within the southwestern square anomaly in both slice (left) and radargram (right) views. The radargram shows the depths below the ground surface at which the anomaly begins and to which it extends.

Area 3

Area 3 is located on the eastern-central portion of the tel, 277.2 m east of area 2. This anomaly is a strong reflection that is rectangular with interior right angles and two distinct circular anomalies (Figure 12). It is 19.84 m by 9.82 m in size. The largest circular anomaly is 1.3 m in diameter. It begins to appear at 0.62 m below ground surface and extends to 1.01 m below the surface.

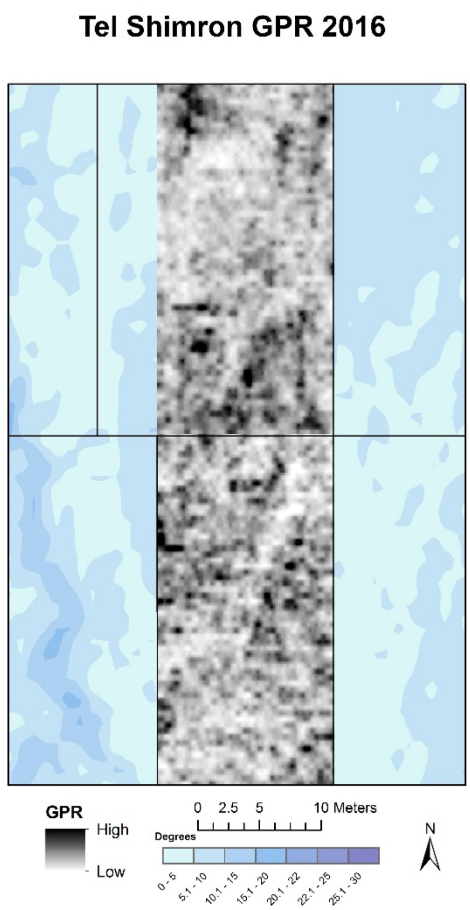

Figure 12. The anomaly in Area 3, which appears at 0.62 m/bs, is a rectangular anomaly with the long edge running north. It has distinct circular reflections within it.

CHAPTER 4

DISCUSSION

Issues Encountered During Data Collection and Processing

While GPR is a highly useful tool for not only locating but also viewing archaeological features in three dimensions (3D), many issues can arise while collecting data in the field and during post-processing. There are two types of reflections generated in GPR data: hyperbolas and planar reflections. Hyperbolas occur from a point source and look like an inverted "U." Planar reflections are linear reflections that typically show a change in subsurface reflection velocity, usually due to a change in chemical composition or grain size (Conyers and Goodman 1997). Feature depth is calculated by estimating the velocity of the radar wave and converting time to distance (Goodman and Piro 2013).

In the field, it is imperative that all cellphones be turned off as incoming or outgoing calls can cause noise in the data. Nearby cell phones and radio noise from walkie-talkies can show up in and interfere with the data, but so can power lines, radio stations, and underground telephone lines that may be within or near the survey area. Such noise can dominate the site to the point that features cannot be resolved (Goodman and Piro 2013). A major source of background noise that was unavoidable during this survey was radio communications from the nearby military base. This introduced a significant amount of noise into the data. Filtering removes or dampens some of the noise in the data. Bandpass filtering allows signals between two specified frequencies to pass, but removes all other frequencies (Goodman and Piro 2013). A general methodology for determining an appropriate high pass filter is to divide the frequency of the transmitter by two; for the low pass filter, the transmitter frequency is doubled (Conyers and Goodman 1997). If interference is within passed frequencies, a notch filter can be used (Figure

13). The notch filter allows the user to a selected a frequency, such as 190 MHz, to remove even if it falls within the Bandpass frequencies (Goodman and Piro, 2009). Notch filtering works the best for this site. By determining the exact frequencies of the noise and the features and then notching out only the frequency of the noise, a significant amount can be removed with minimal impact on the visualization of the features. The background removal filter removes horizontal banding so that the feature will be more evident in the data (Goodman and Piro 2013).

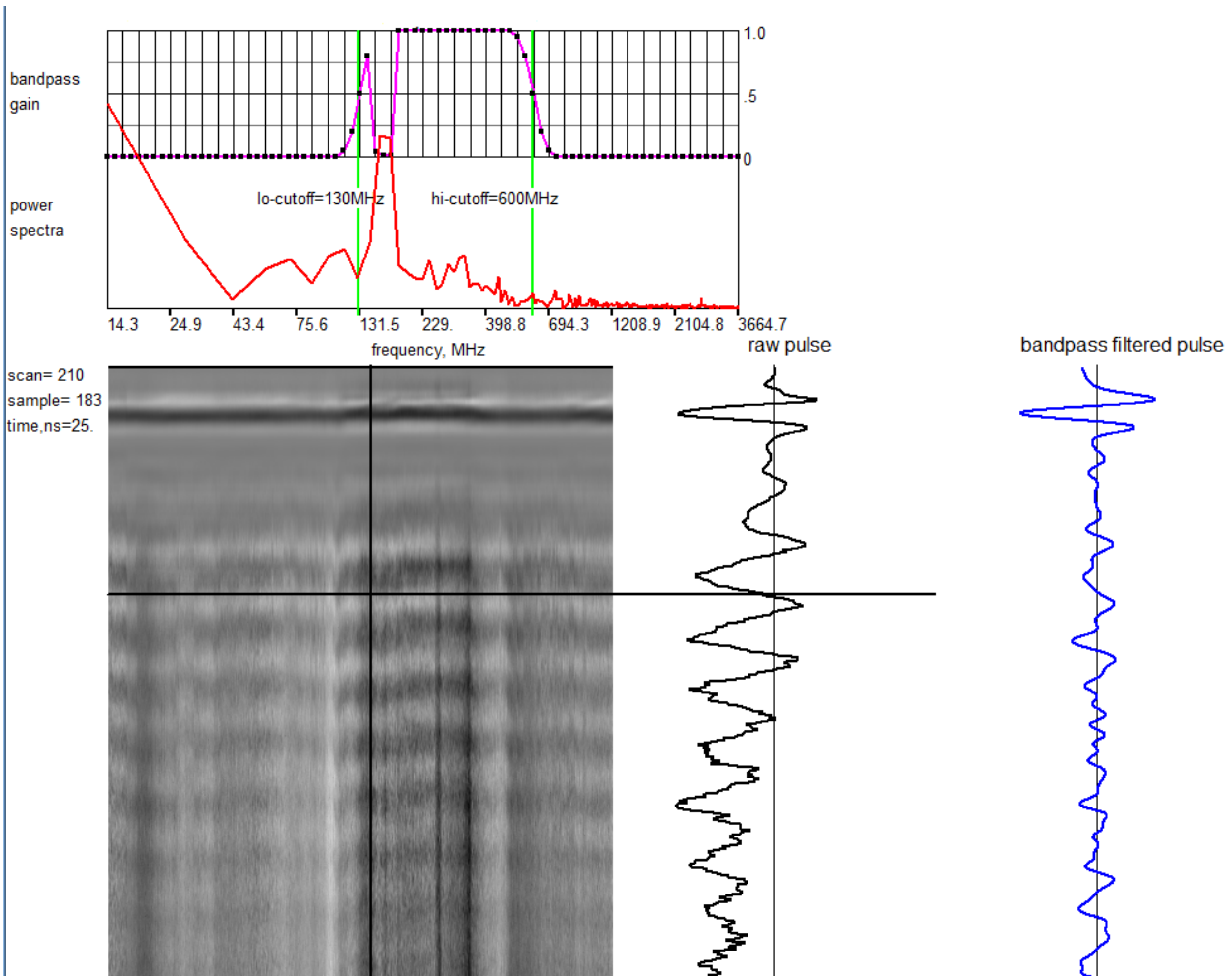

Figure 13. The notch filter, seen above in the pink line, allows the user to "notch out" a selected frequency that the Bandpass filter permits.

None of the filters are fully able to remove all of the noise. This partially attributable to some features occuring at the same frequency as noise so noise cannot be removed without removing the features from the data. Noise at the deepest part of the time window is static, like white noise on a radio It is important then to recognize that the reflections appearing in the deepest part of the data are not features, but rather simply amplified noise.

Due to the high volume of modern trash such as rebar, coins, car parts, and street signs left on the tel, the magnetometry survey required collecting trash off of the surface of the tel prior to data collection. As surface metal would obscure the subtler sub-surface features that were the target of the survey, it was important that all of the metal trash was removed that could be removed from the survey area. Additionally, the surveyor carrying the magnetometer was required to be free of car keys, metal zippers, metal buttons, and other similar items.

Data processing with magnetometry is considerably less involved than with GPR. However, there are filters and analysis that can be run to improve visualization of data. De-striping removes striping along the traverse by balancing the differences between sensors. These vertical stripes are present in the data because the Bartington has two sensors that have been tuned independently of one another and so have two different zero points. Staggering in the data occurs when the researcher collecting the data in the field walks too fast or too slow for the pace set per meter. This can be fixed using a de-stagger tool. In areas that have been plowed, such as the lower field on the western end of the tel, a Fourier analysis helps remove plow marks.

Landscape-Scale Reconnaissance Surveys

Geophysics has long been used to study archaeological sites (Carcione 1996; Conyers and Goodman 1997; Conyers 2006; Goodman and Piro 2009). Early surveys covered tens of square meters, and showed the great potential and advantages of these methodologies in archaeology. For example, one of the earliest geophysical prospections in archaeology in the United States was an equipotential survey, similar to a resistivity survey, at a churchyard on the historic site of Colonial Williamsburg in 1938 in an attempt to locate a stone vault. The vault was not identified, but a strong resistivity anomaly was noted (Bevan 2000). In 1993, approximately 200 square meters were surveyed with a dual-bottle proton magnetometer across 6 sites at Indian Camp Ranch, with no one site surveyed for more than 50 square meters. The survey identified a small kiva community with pithouses and middens (Baker and Brooks 1993). Over the years, instruments and computing power have continuously improved, making landscape-scale geophysical surveys possible by the early 2000s (Kvamme 2003). The most recent advance in archaeological geophysics is the development of GPS-enabled multi-sensor cart systems. It is now common to use magnetometer carts as a reconnaissance tool because they can cover the largest area in the shortest amount of time, often with stunning results (Bruseth et al, 2007; Walker 2009, Ullrich et al. 2011). Magnetometers are ideal for cart deployment because the sensors do not touch the ground, allowing surveys over moderately rough terrain that would not be amenable other sensors such as GPR antennas. Additionally, magnetometry datasets are two-dimensional images that represent a single depth range, making them much faster to process and interpret compared to GPR and electromagnetic induction (EMI).

EMI is also used at a landscape scale by towing sensors, with integrated global navigation satellite system (GNSS) positions, behind motorized vehicles. For example, Saey et al. (2015) used an EMI pulled by an all-terrain vehicle to study the site of Stonehenge in the UK. Specifically, the researchers were interested in historic components of the site dating to World War I and located a trench used for military training. However, data processing and interpretation is more time-consuming and complex compared to magnetometry. Many EMI instruments simultaneously measure conductivity and magnetic susceptibility, doubling the number of datasets produced from a single sensor. In addition, many sensors employ multiple transmitter-receiver pairs that make these measurements at multiple depths, therefore adding many more layers of data. Finally, there is a tendency for EMI signals to be inverted at greater depths, adding a level of complexity to data interpretation (Tabbagh 1986). Landscape-scale EMI data are therefore a more time-consuming method when compared to magnetometry, but still a useful tool for reconnaissance surveys (Tabbagh 1986). It may be a better choice than magnetometry, however, depending on the nature of the site and its geological context.

Increasingly, GPR is also being used at the landscape scale. In some cases, where time is not a limiting factor, people have surveyed very large areas with GPR. A 1.2 hectare survey of Pueblo Escondido provided details on the organization of a large pueblo village (Ernenwein 2008). An area of 6 hectares at Tell Qubr Abu al-Atiq in Syria was surveyed using a 250 MHz antenna. Despite significant attenuation due to high clay content soil, structures from the lower city including a basalt and brick wall were identified (Novo et al. 2014).

More recently, GPR arrays have emerged for rapid, large-area surveys. The use of a GPR system on a motorized platform with its location tracked by an RTK-GPS is one example of this. Such setups decrease collection time as well as time spent at a computer georeferencing results (Birken et al. 2002; Leckebusch 2005). The World Heritage Site of Stonehenge was surveyed with a multi-array GPR cart, covering 1.7 hectares with the goal of locating early 20th century historic features. An infilled WWI trench system was located on the site (Saey et al. 2015). Francese et al. (2009) investigated a 7.5 hectare Roman site in Italy using a GPS-enabled GPR cart. A Roman villa with interior rooms was identified by the radar on the northern portion of the site. At Mound City, a Hopewell site in the Ohio River Valley, a GPR array was used to survey 640 square meters and identified clay loam in preserved pits (Schneider et al. 2016)

There is no question that GPR array systems offer great advantages and allow large areas to be surveyed at very high resolution over a relatively short period of time. Data processing and interpretation, however, are much more demanding in terms of time and computing power when compared to magnetometry and EMI. Not only are GPR data files orders of magnitude larger, they also contain significantly more detail owing to their three-dimensional nature. The time needed to fully process and interpret GPR data is at least four times that required for magnetometry data for the same sized area.

Given that technology now provides the capability to do reconnaissance-level survey of very large areas with magnetometry, EMI, and GPR, there is now an ethical dilemma. If time is limited, should large area GPR survey be used as a reconnaissance tool? Or should it not be used unless sufficient time can be dedicated to processing and interpretation? The situation at Tel Shimron, described below, addresses these questions. When GPR is deemed the best possible geophysical method, using it for reconnaissance-level survey is the best approach. This includes automated or semi-automated processing and use of time slices as the primary data product, even though details inherent in the data are lost in the process. Relying solely on the time slices is equivalent to relying on other sensors that only provide this less-detailed view of subsurface properties. Amongst archaeological geophysicists, there would be no objection to using magnetometry or EMI across the site, even though these data are limited in their level of detail and precision compared to GPR. A benefit to our approach is that the full resolution of the GPR data remains intact for future examination and investigation of targeted areas.

A Reconnaissance Tool for Tel Shimron

Magnetometry and ground penetrating radar measure different physical properties. While GPR measures electrical conductivity, it usually doesn't measure changes in magnetism. Likewise, magnetometry is a valuable tool for measuring magnetic susceptibility but typically will not identify changes in electrical properties. Because of this, they are typically complementary methods used to study archaeological sites (Kvamme 2003). One of GPR's most appealing traits is the ability to see by depth, while with magnetometry the primary advantage is the speed and ease that data can be collected. Not every feature may be detectable by one of the methods, so by using multiple geophysical methods, the likelihood of identifying the presence of most features at a site is maximized. However, when one method doesn't work well at a site, it is important to collect data with an instrument that can provide quality landscape-scale reconnaissance information.

For landscape-scale reconnaissance surveys, the commonly accepted tool is magnetometry as it typically can provide fast, high quality results (Kvamme 2003; Bruseth et al. 2007; Walker 2009; Ullrich et al. 2011). The speed at which magnetometry data can be collected is limited only by the walking speed of the person collecting the data. This offers an advantage over GPR, which is considerably slower, both during data collection and data processing. However, there are circumstances and situations where magnetometry data will not show as much detail as GPR or provide the quality of results expected in a reconnaissance survey. Tel Shimron is one instance where this is the case. Due to the high volume of ferrous trash and metal structures on the surface of the tel along with the nearby basalt quarries, the magnetometry data does not provide adequate results for a reconnaissance survey.

Magnetometry proved useful only in certain areas such as area 1 of Tel Shimron, though it required cleaning of the surface prior to data collection due to the high volume of modern metal trash left on the tel. Items such as rebar, coins, car parts, and street signs were found in the area to be surveyed. Because the metal on the surface would obscure the subtler buried features that were the target of the survey, all metal trash that could be removed from the survey area was removed. This took a significant amount of time and energy away from data collection.

Additionally, a significant amount of unmovable metal objects was present on the tel. Despite these efforts, magnetometry revealed little about subsurface archaeological features compared to GPR. Conventional wisdom would suggest that magnetometry would have been the preferred method given the speed at which it can be collected, but due to the circumstances of the tel, GPR provided a superior dataset.

The GPR data offers far more detail and provides a higher standard of results than magnetometry. Where the magnetometer was not able to resolve features, the GPR identified several probable features, including the Bronze Age and Iron Age dwellings and the Bronze Age Gate discussed in this thesis. While some researchers may argue that GPR should not be used as a reconnaissance tool because the adequate time cannot be devoted to processing and analyzing, this is not the case with Tel Shimron. Data were processed in real time and extensively analyzed to determine spatial occupation patterns and sites of probable features to be further studied. The data will also be available now for future research to compare to excavation results as well as to identify additional areas to excavate if needed. Thus, GPR proved to be an excellent reconnaissance tool for Tel Shimron and was more powerful than magnetometry. It not only provided information about depth, but also detected significantly more features. GPR, then, should be considered as a reconnaissance tool for future landscape-scale geophysical surveys.

Data Interpretation

Pedestrian Survey to Inform Geophysical Interpretations

A pedestrian survey following Portugali's field methods from his 1981 survey of Tel Shimron (Portugali 1982) was conducted at the beginning of the 2016 field season. Surface ceramics were collected from 10 x 10 m grids and then analyzed to determine which cultural period was the predominant type for that grid. These pottery readings provided us with probable most recent occupations for the various locations on the tel (Figure 14), which were then used to provide information about specific architecture that should be present in that given area. Area 1 and 2 are in locations identified as Middle Bronze Age and Area 3 is in a location identified as Iron II (Figure 15).

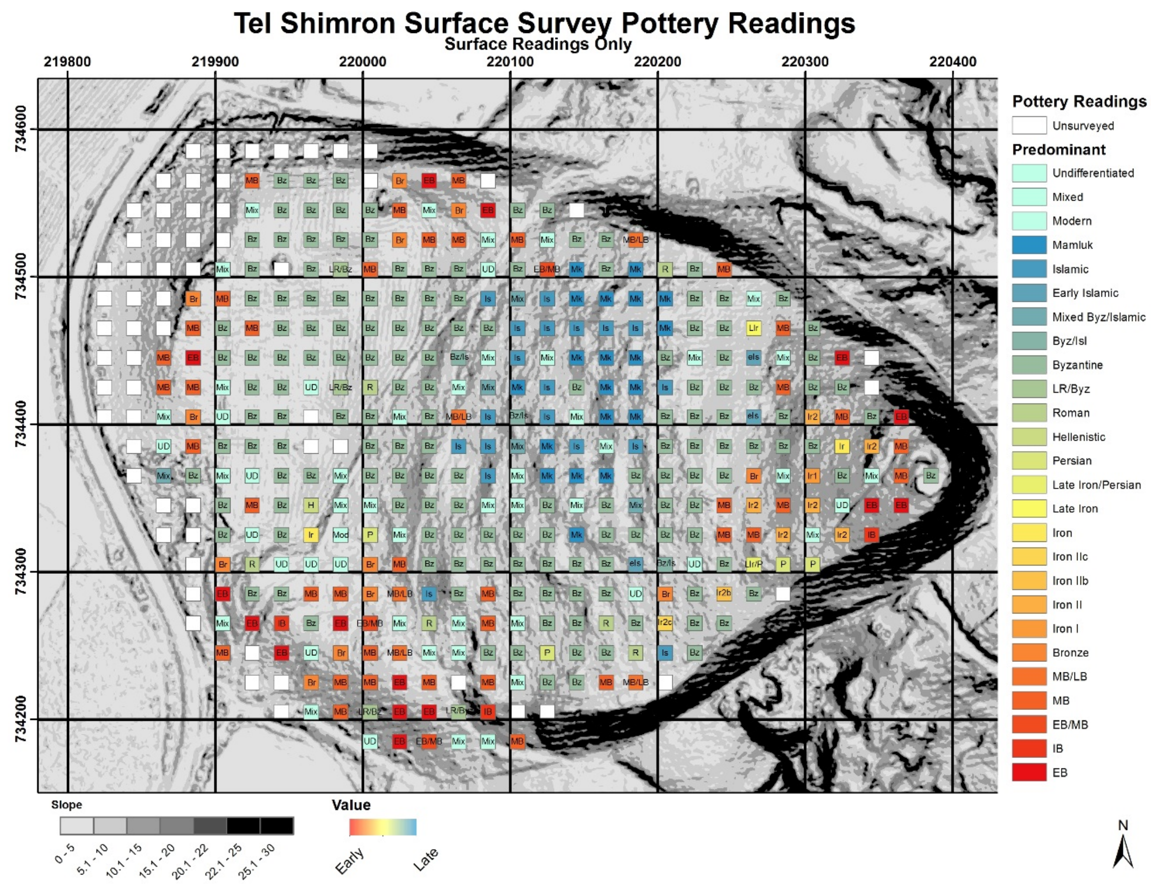

Figure 14. Results of the pedestrian surface survey and pottery readings. Predominant occupation periods were determined by surface ceramic readings and suggest probable most recent occupation for that 10 x 10 m grid. Courtesy of Tel Shimron Excavations and E. Laugier.

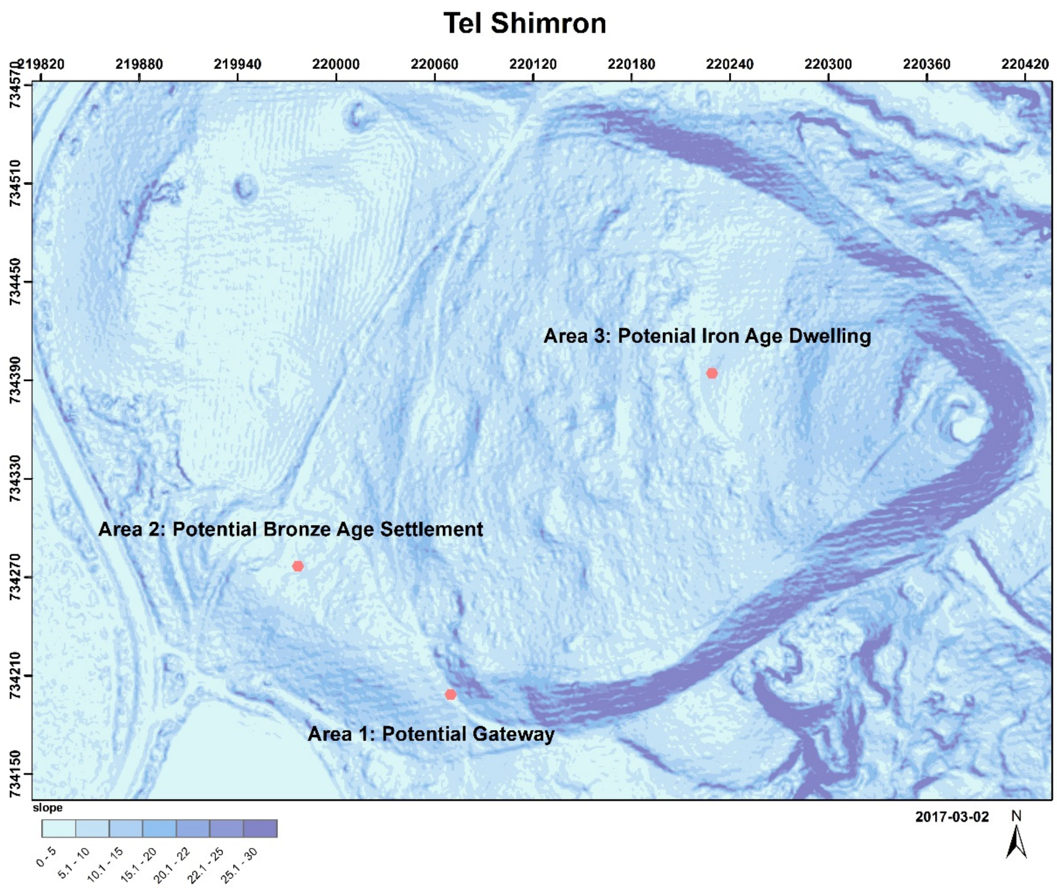

Figure 15. Map depicting the locations of Areas 1, 2 and 3 on Tel Shimron.

Architecture in the Study Region

With the Middle Bronze Age comes a reappearance of urbanization in the Jezreel Valley, bringing about rapid construction of fortified or walled cities (Kempinski 1992). Fortifications are a prominent aspect of larger cities in the Levant during the Middle Bronze Age. The ramparts provide protection and the gate acts not only as a limited entrance and exit point, but also as a center of commerce and social gathering. As such, the gate is an important location for both Bronze and Iron Age societies and of great interest to archaeologists.

Architecture of the Levant in the Bronze Age has been well-documented by previous excavations (Kempinski 1992; Oren 1992;). Residences of the wealthy class, such as palaces, patrician houses, and governor's residences, are typically more complex, larger, and rich in terms of material finds than the average dwelling (Oren 1992). Often consisting of interior partitions that may be living quarters, corridors, service quarters, store rooms, or courtyards, these residences are commonly located in the general city plan near the gate (Oren 1992). Courtyards occasionally have columns and/or capitals. Additionally, water sources, such as wells, and drainage systems are often present in these residences (Oren 1992). An example of such architecture is illustrated in Figure 16.

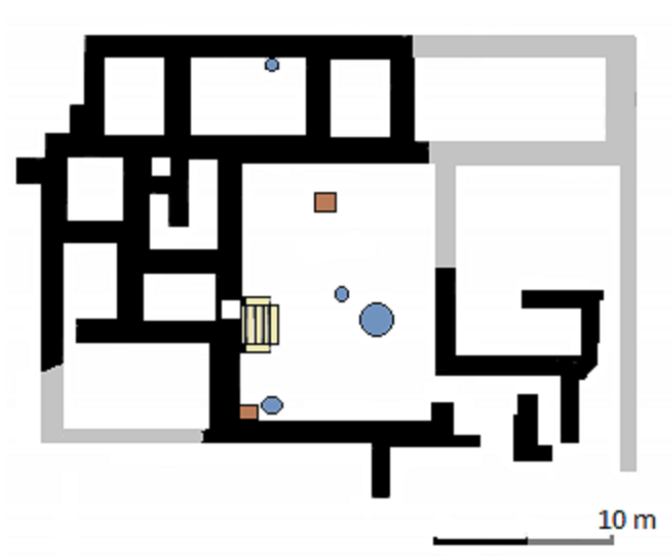

Figure 16. The palace from Megiddo VIII showing interior partitions, columns (blue), and stairs (yellow). Black lines are intact walls and gray lines are suspected walls. Adapted from Oren (1992).

A new structure of private dwelling emerges in the Iron Age. These oblong or square features usually have a main, central space with one to three additional rooms built at right angles from the main room (Netzer 1992). This multi-room dwelling has been termed the "Israelite house" by Y. Shiloh (Shiloh 1973) or "four-room" house, which is preferable today.

The earliest of these types of houses is believed to be a late 13th century BC dwelling at Giloh and two houses at Tel Masos, all of which are believed to have courtyards and a row of pillars (Netzer 1992). However the shape of the courtyard and number of pillars do not appear to be uniform across sites. Notably, there is discussion amongst scholars that the rooms believed to be courtyard may actually be open air rooms that would have been covered by a second story roof (Netzer 1992). Regardless, the uniform components of these dwellings are oblong partitions and occasionally an interior row of pillars, as shown in Figure 17.

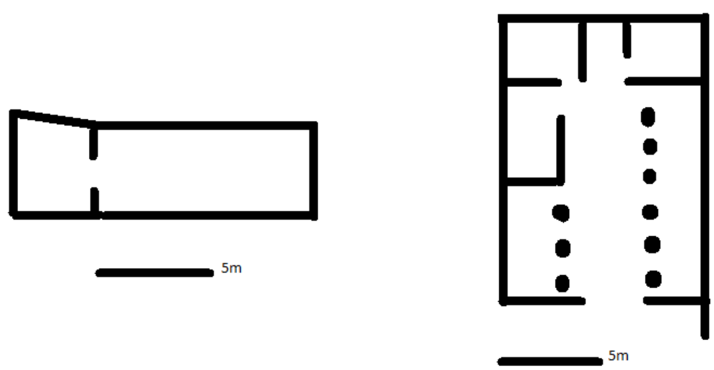

Figure 17. Two examples of Israelite houses from the Iron Age with interior partitions and columns. Adapted from Netzer (1992)

Interpretations of Geophysical Data

Area 1: Potential Bronze Age Gate. Large basalt boulders lie on the southern rampart of the tel (Figure 18). It is likely that this spot used today to access the rest of the site is the same location of the gateway used to access a fortified Bronze Age city located just within its walls. The GPR and magnetometry data for this area support the theory that more basalt boulders may be present beneath the surface.

Figure 18. On the surface of the tel are several large basalt boulders.

The GPR data shows a series of interlocking lines that meet a few meters to the west of the basalt boulders (Figure 19). The lines could form one side of the interlocking chamber gateway that would be present at a fortified Bronze Age settlement. Reflections begin to appear in the data at a very shallow depth and as such are fairly close to the surface. Magnetometry had extremely high and low signals, causing the data to look “blown out” (Figure 19). This could be due to the basalt boulders a few meters away on the surface but is likely also related to additional basalt structures below the surface. These basalt boulders would have been ideal in a protective structure.

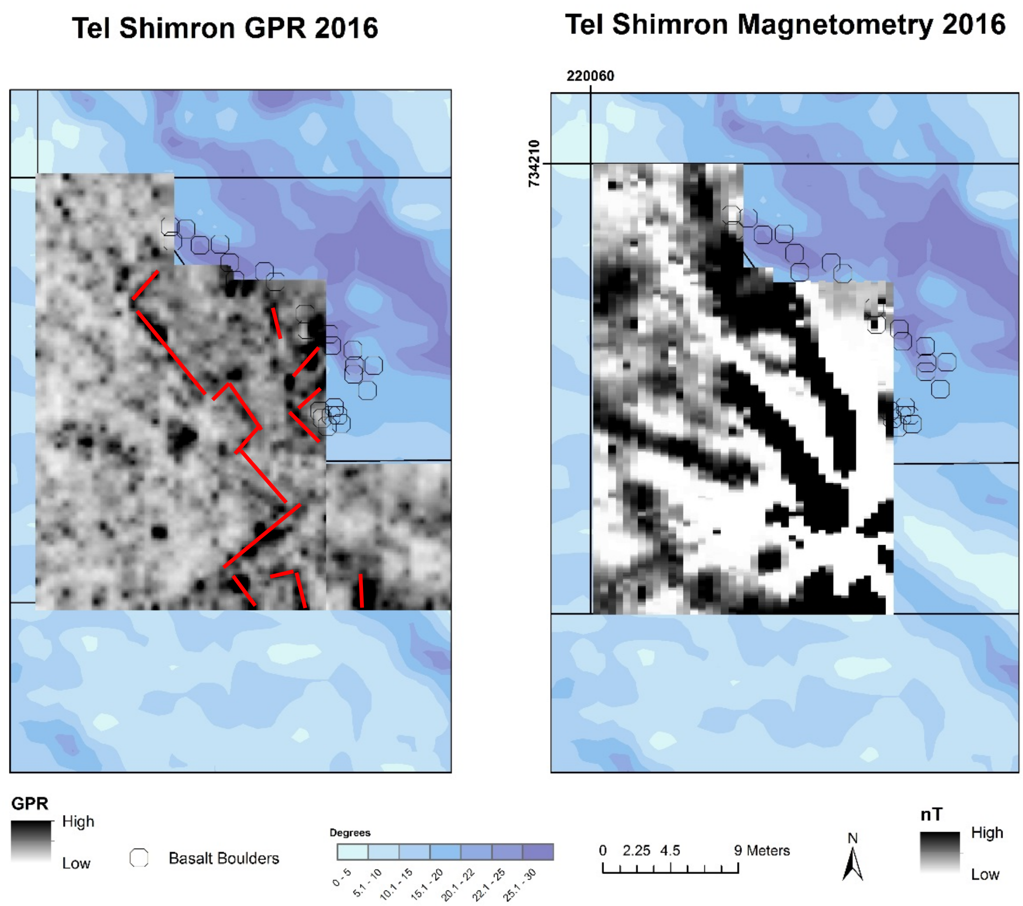

Figure 19. GPR and magnetometry data in Area 1, the southwest of the tel, show an anomaly that is the probable gate**.**

Area 2: Potential Bronze Age Dwelling. This anomaly appears to have numerous small squares and rectangles off to the southern, western, and northern edges of a primary rectangular structure (Figure 20), suggesting an architecturally complex dwelling with many interior rooms. Circular features within the anomaly may be pillars or wells. Given the complexity that appears to be present in the feature and its location just inside what is believed to be the Bronze Age gate (Figure 15, it is highly possible that the structure could be a patrician house or palatial structure. Gaps in between the reflections could be due to deterioration or damage to the structure. Additionally, several circular anomalies are present in this area of the grid as well.

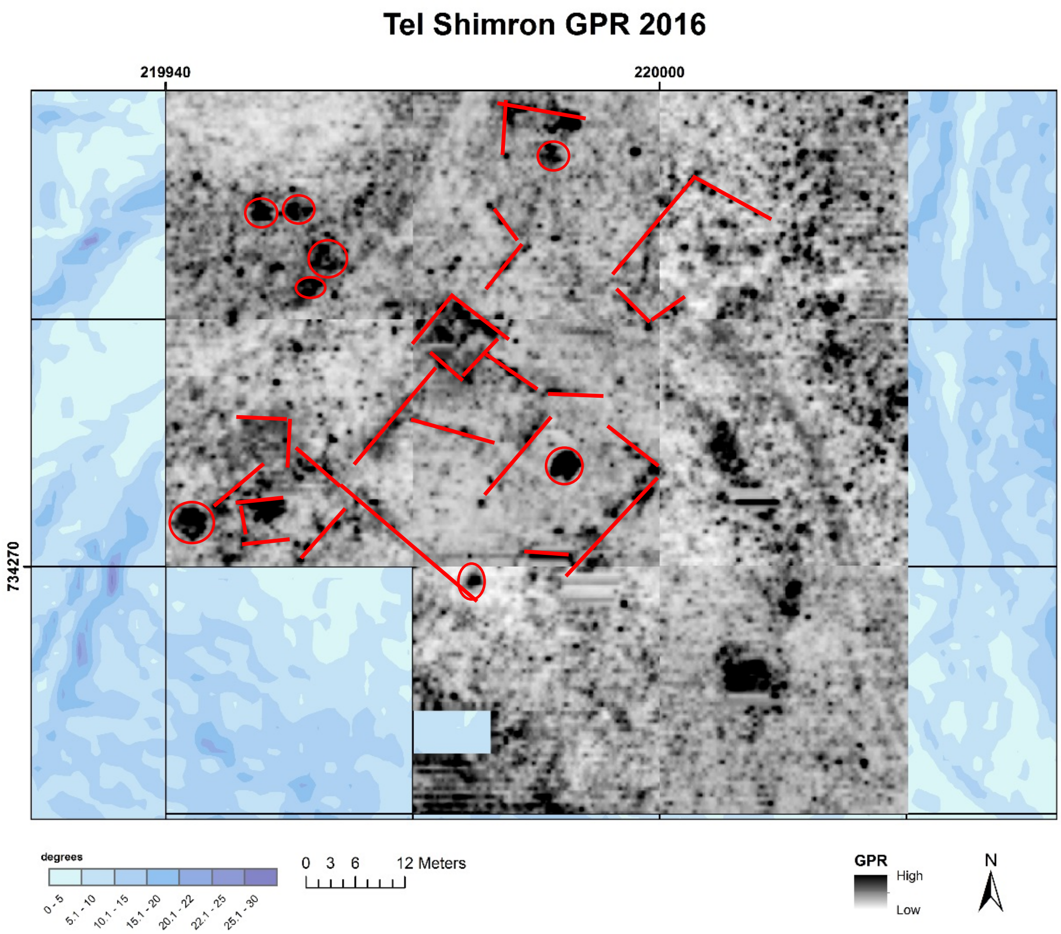

Figure 20. Anomaly with walls (red lines) and potential pillars, columns, or wells (red circles). This could be a Bronze patrician or palatial structure.

The surface of this portion of the tel had a high volume of metal debris. Magnetometry in this area does not show the features described in Figures 8 and 9 because of the magnetic signature of nearby piles of metal signs, car parts, and roofing (Figure 21). This debris "overpowers" any archaeological feature below the grounds surface. Additionally, modern vehicle paths along the tel cause areas to obscure much of what would be below the surface so that anomalies cannot be seen.

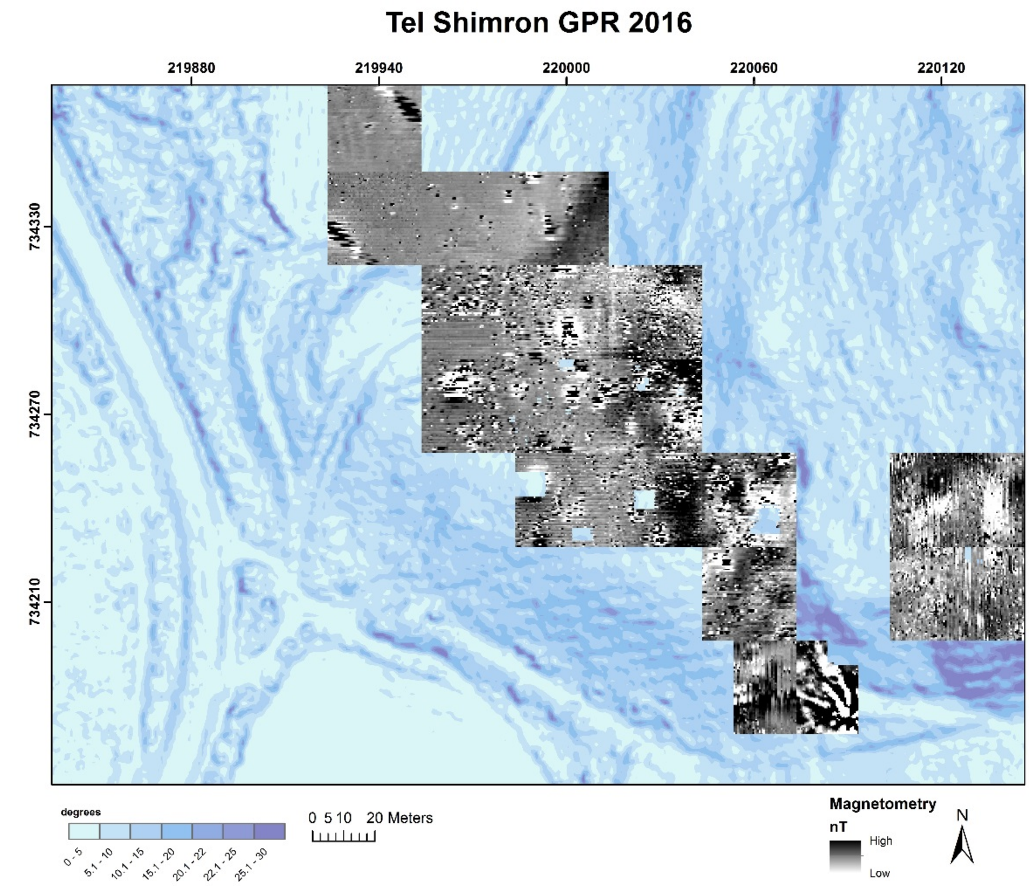

Figure 21. Magnetometry for the southwest of the tel showing intense surface metals that overpower the survey.

Area 3: Iron Age Dwelling. Another noteworthy anomaly appears three-quarters of the way up to the acropolis on the eastern portion of the tel. As shown in Figure 22, the anomaly is present in the GPR, but not the magnetometry data. It is an approximately 15 m by 10 m square feature that appears to have partitions. There is a possibility that the stronger reflection in the center of the feature could be pillars or columns like those described by Netzer (1992) discussed previously in this article. Interestingly, the anomaly does not appear in the magnetometry. Pedestrian survey of this area indicated a heavy presence of Iron Age ceramics. Given its location, square shape, potential partitions or rooms, and potential presence of pillars, this anomaly is anticipated to be what was previously defined as an “Israelite house”/ four-room house.

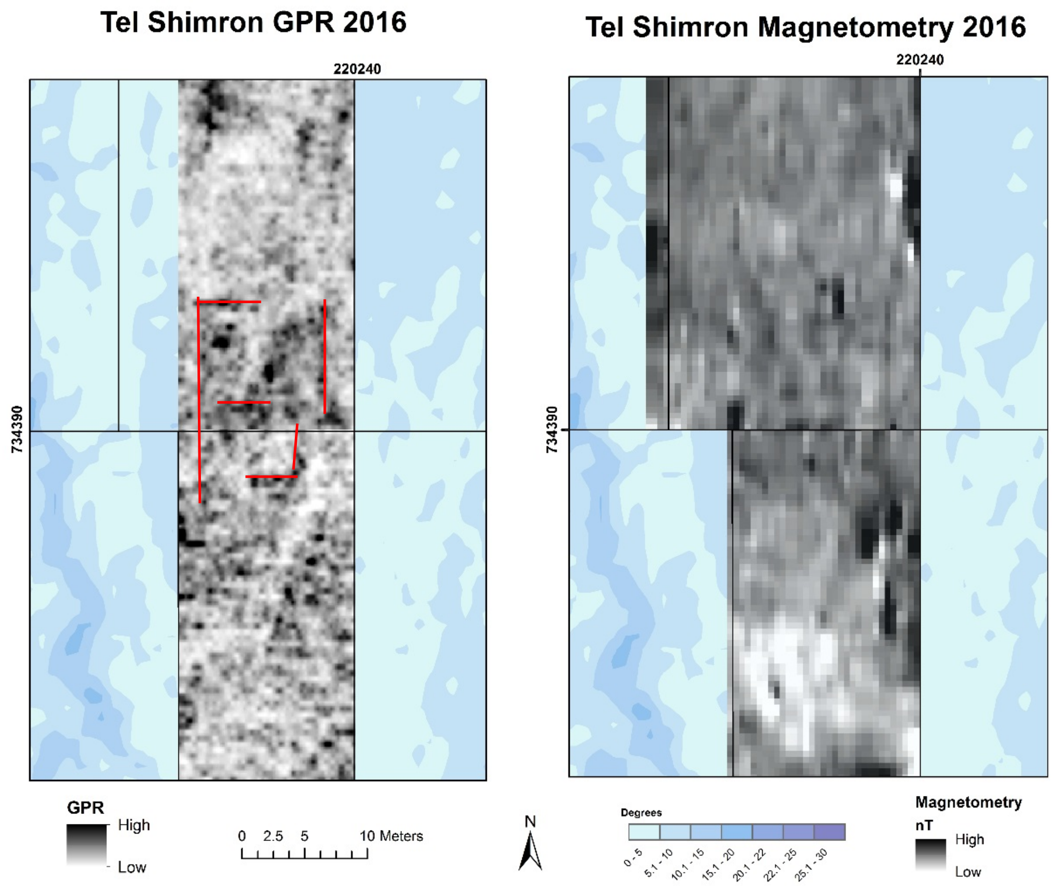

Figure 22. A rectangular anomaly is apparent in the GPR data, but not the magnetometry. In the GPR the extent of the probable Iron Age dwelling is illustrated using red lines.

CHAPTER 5

CONCLUSION

Geophysical surveys offer a variety of advantages for the exploration of archaeological sites. As a non-invasive method for archaeological prospection, geophysics and near-surface remote sensing provide the capabilities to collect data over a large area in a relatively short period without damaging the site. Because of this, archaeologists can study the spatial layout of the site as a whole and can better describe settlement and occupation patterns. The survey of Tel Shimron utilized magnetometry and ground penetrating radar to map the extent of the site and locate areas of occupation on the upper strata of the tel. Through a two team field method and a real-time, on-site data processing methodology, the amount of work completed during the six-week data collection season was maximized and proved effective for work at Tel Shimron. The survey yielded positive results, identifying several potential features and areas of occupation on the tel.

As non-invasive methods for archaeological prospection, magnetometry and GPR provide the opportunity to collect data on a large area in a relatively short period of time without excavating. Because of this, archaeologists can study the spatial layout of the site as a whole, allowing for the discussion of settlement and occupation patterns. The survey of Tel Shimron utilized magnetometry and GPR to map the extent of the site and locate areas of occupation on the upper strata of the tel. Through evaluation of the processed data, the outline and structure of potential features can be viewed and then compared to known features at nearby sites to predict the feature types. Based on surface architecture and strong reflections suggesting a chambered entryway surrounded by walls running east-west as well as north-south, it is highly likely that the Bronze Age gate into the fortified city was located on the southwestern edge of the tel. This survey identified anomalies that may be one large or two smaller Bronze Age dwellings just inside this gate. The GPR also identified a probable “Israelite” house on the Eastern-central portion of the tel.

GPR offered more detail and was able to identify more probable features than magnetometry, which was negatively impacted by the surface factors on the tel. Ferrous metals in trash left on the tel as well as buildings and platforms reinforced with ferrous metal obscured the magnetometry data. Where probable features were seen in the GPR, such features were not identified in the magnetometry data. Despite being a traditionally slower geophysical method, 6 hectares of GPR data were collected at Tel Shimron during the field season, proving that the technique can be used as a landscape-scale reconnaissance tool. The identification of probable dwellings and a gateway suggest that the GPR was successful in resolving features, even when the magnetometry was not.

When considering the usefulness and success of the methods individually, data from the ground penetrating radar is relied more heavily upon, despite magnetometry being quicker and easier to process. The removal of surface metal trash took both time and manpower away from data collection and not all metal trash was able to be removed. Additionally, metal structures on the surface such as signs, rebar, and a building had such a strong magnetic field that they overpowered the surrounding areas, obscuring the data to the point that it is highly plausible that features are being missed. The ground penetrating radar, though admittedly slower in terms of both data collection and data processing, offered more detailed results. The rich data from the GPR can now be added to Tel Shimron’s archive, available for future, additional interpretation as the archaeologists open up more excavation units in new areas in the future.

REFERENCES

"GPR-Slice V7.0 User's Manual." GPR-Slice Software. 20 February 2017. Web. Accessed 5 June 2-17.

אחיטוב, שמואל, Ahituv, S. 1981. The Lebanon, Galilee and Bashan in a Topographical List of Amenhotep III / הלבנון, הגליל והבשן ברשימה טופוגרפית של אמנחתפ השלישי. Eretz-Israel: Archaeological, Historical and Geographical Studies / ארץ-ישראל: מחקרים בידיעת הארץ ועתיקותיה,.

Albright, WF. 1925. Bronze Age Mounds of Northern Palestine and the Hauran: The Spring Trip of the School in Jerusalem. *BASOR.* 19:5–19.

Baker, HE, Brooks, B. 1993. Geophysical Surveys of Anasazi Ruins, Indian Camp Ranch, Cortez, Colorado. ProQuest Dissertations and Theses. Accessed 3/05/2017.

Bevan, BW. 2000. An early geophysical survey at Williamsburg, USA. *Archaeological Prospection* 7(1): 51–58.

Birken, R, Miller, DE, Burns, M, Albats, P, Casadonte, R, Deming, R, Derubeis, T, Hansen, T, Oristaglio, M. 2002. *9th International Conference on Ground Penetrating Radar, Expanded Abstracts.* p. 186-191.

Boyce, JI, Reinhardt, EG, Raban, A, Pozza, MR. 2004. The utility of marine magnetic surveying for mapping buried hydraulic concrete harbour structures: marine magnetic survey of a submerged Roman harbour, Caesarea Maritima, Israel. *The International Journal of Nautical Archaeology.* 33(1): 122–136.

Bruseth, J, Pierson, W, Johnson, R. 2007. Large-Area Remote Sensing Coverage of Archaeological Sites with a Dual-Track, Cart-Mounted Cesium Magnetometer. *Journal of Field Archaeology. 32*(2): 133-148.

Carcione, JM. 1996. Ground radar simulation for archaeological applications. *Geophysical Prospecting.* 44: 871-888.

Casana, J, Herrman, J, Fogel, A. 2008. Deep subsurface geophysical prospection at Tell Qarqur, Syria. *Archaeological Prospection.* 15(3):207-225

Clark, Anthony J. 1996 Seeing Beneath the Soil. Prospecting Methods in Archaeology. London, United Kingdom: B.T. Batsford Ltd.

Conyers, LB, Goodman, D. 1997. Ground-Penetrating Radar: An Introduction for Archaeologists. AltaMira Press:Walnut Creek, CA.

Conyers, LB, Ernenwein, E, Bedal, L. 2002. Ground Penetrating Radar Discovery at Petra, Jordan. *Antiquity.* 76(292): 339-340.

Conyers, LB. 2006. Ground-penetrating Radar. *Remote Sensing in Archaeology*. Edited by Jay K. Johnson. Tuscaloosa, Alabama: The University of Alabama Press, pp. 131-16.

Covello-Paran, K. 2015. *The Jezreel Valley During the Intermediate Bronze Age: Social and Cultural Landscapes.* Ph.D thesis, Tel Aviv University.

Dolphin, LT. 1981. Geophysical methods for archaeological surveys in Israel. Menlo Park, CA: Stanford Research International.

Ebeling, J, Franklin, N. 2016. Jezreel Expedition 2016: Jezreel Through Time. *Archaeology Today.* Biblical Archaeology Society. http://www.biblicalarchaeology.org/daily/archaeology-today/jezreel-expedition-2016-jezreel-through-time/

Eppelbaum, L. 2010. Archaeological geophysics in Israel: Past, present, and future. *Advances in Geosciences.* 24:45-68.

Ernenwein, EG. 2008. A Geophysical View of Pueblo Escondido: Implications for the Pithouse to Pueblo Transition in the Jornada Mogollon. *Bulletin of the Texas Archaeological Society.* 79:125-145.

Faust, A, Katz, H, Eyall, P. 2015. Late Persian – Early Hellenistic Remains at Tel 'Eton: A Preliminary Report (2006-2014). *Tel Aviv.* 42: 103-126.

Finkelstein, I, Ussishkin, D, Halpern, B. 2006. Megiddo IV: The 1998-2002 Seasons. Tel Aviv: Emery and Claire Yates Publications in Archaeology. Pp. 705-777.

Frances, R. 2013. The three-arched middle Bronze Age gate at Tel Dan - A structural investigation of an extraordinary archaeological site. *Construction and Building Materials.* 41: 950-956.

Francese, RG, Finzi, E, Morelli, G. 2009. 3-D high-resolution multi-channel radar investigiation of a Roman village in Northern Italy. *Journal of Applied Geophysics.* 67(1): 44-51.

Gal, Z. 1992. Lower Galilee during the Iron Age. Winona Lake, IN: Eisenbrauns.

Gerard-Little, P, Rogers, M, and Jordan, K. 2012. Understanding the built environment at the Seneca Iroquois White Springs Site using large scale, multi-instrument archaeological surveys. *Journal of Archaeological Science.* 39:2042-2048.

Gilboa, A, Sharon, I. 2008. Between the Carmel and the Sea: Dor’s Iron Age Reconsidered. *Near Eastern Archaeology.* 71(71): 47-79.

Goodman, D, Piro, S. 2009. Ground Penetrating Radar (GPR) Survey at Aiali (Grosseto). *Seeing the Unseen*. Edited by S. Campana and S. Piro. London: Taylor and Francis Group. p. 297-302.

Hanan, G, Rybakov, M, Shirman, B, Lazar, M. 2014. Magmatic occurrences in the Central Arava (southern Israel) based on Geology and Magnetometry. *Journal of Asian Earth Sciences.* 85:106-116.

Ilan, Z. 1991. Ancient Synagogues in Israel. Tel Aviv: משרד הבטחון.

Johnson, JK. 2006. Remote Sensing in Archaeology: An Expicitly North American Perspective. Tuscaloosa: University Alabama Press.

Johnston, B, Hua, Y, Cothren, J. 2006. *ArchaeoFusion User's Manual*. Fayetteville, AR: Center for Advanced Spatial Technologies, University of Arkansas.

Josephus. Wars of the Jews. Whiston: Lexundria: A Digital Library of Classical Antiquity. Accessed 3/17/2017.

Kempinski, A. 1992. Urbanization and Town Plans in the Middle Bronze Age II. The Archaeology of Ancient Israel: From the Prehistoric to the Persian Period. Edited by Aharon Kempinski and Ronny Reich. Jerusalem, Israel: The Israel Exploration Society. p.121-126.

Killebrew, AE. 2005. Biblical Peoples and Ethnicity: An Archaeological Study of Egyptians, Canaanites, Philistines and Early Israel. Atlanta, GA: Society of Biblical Literature.

Kvamme, K. 2003. Geophysical Survey as Landscape Archaeology. *American Antiquity.* 68(3):435-457.

Lane, MF, Horsely, TJ, Charami, A, Bittner, WS. 2016. Archaeological geophysics of a Bronze Age agricultural landscape: the AROURA Project, central mainland Greece. *Journal of Field Archaeology.* 41(3):271-296.

Leckebusch, J. 2005. Precision real-time positioning for fast geophysical prospection. *Archaeological Prospection.* 12: 199-202.

Leucci, G, DeGiorgi, L, Scardozzi, G. 2014. Geophysical prospecting and remote sensing for the study of the San Rossore area in PIs (Tuscany, Italy). *Journal of Archaeological Science.* 52: 256-276.

Marom, N. 2014. Relating a city's history and geography with Bourdieu: One hundred years of spatial distinction in Tel Aviv. *International Journal of Urban and Regional Research.* 38(4): 1344-1362.

Novo, A, Solla, M, Fenollos, JM, Lorenzo, H. 2014. Searching for the remains of an Early Bronze Age city at Tell Qubr Abu al-Atiq (Syria) through archaeological investigations and GPR imaging. *Journal of Cultural Heritage.* 15: 575-579.

Oren, ED. 1992. Palaces and Patrician Houses in the Middle and Late Bronze Age. The Archaeology of Ancient Israel: From the Prehistoric to the Persian Period. Edited by Aharon Kempinski and Ronny Reich. Jerusalem, Israel: Israel Exploration Society. p.105-120.

Portugali, Y. 1982. A Field Methodology for Regional Archaeology (The Jezreel Valley Survey, 1981). *Tel Aviv* 9: 170–88.

Raban, A. 1982. Archaeological Survey of Israel: Nahalal Map. Jerusalem, Israel: Archaeological Survey of Israel. p. 16-23.

Saey, T, Van Meirvenne, M, de Smedt, P, Stichelbaut, B, Delefortrie, S, Baldwin, E, Gaffney, V. 2015. Combining EMI and GPR for non-invasive soil sensing at Stonehenge World Heritage Site: the reconstruction of a WWI practice trench. *European Journal of Soil Science.* 66:166-178.

Scheider, BB, Mandel, RD, Tsoflias, GP, De Vore, SL, Lynott, M. 2016. Combining ER and GPR surveys for evidence of prehistoric landscape construction: case study at Mound City, Ohio, USA. *Journal of Applied Geophysics.* 129:178-186.

Sharfstein, S. 1994. *Understanding Israel*. Hobeken NJ: KTAV Publishing House.

Shiloh, Y. 1973. The Four-Room House - The Israelite TypeHouse, *EI II.* pp. 277-285.

Strange, JF. 2014. The Galilean Road System. Galilee in the Late Second Temple and Mishnaic Periods: Life, Culture, and Society, Volume 1, edited by David A. Fiensy and James Riley Strange. Minneapolis: Fortress Press. p. 263–71.

Tabbagh, A. 1986. What is the Best Coil Orientation in the Slingram Electromagnetic prospecting Method? *Archaeometry.* 28(2): 185–196.

Ullrich, Burkart, Kaufman, G, Kniess, R, Zoellner, H, Meyer, M, Keller, L. 2011. Geophysical Prospection in the Southern Harz Mountains Germany: Settlement History and Landscape Archeology along the Interface of the Latene and Przeworsk Cultures. *Archaeological Prospection.* 18(2):92-104.

Urban, T, Rowan, YM, Kersel, MM. 2014 Ground-penetrating radar investigations at Marj Rabba, a Chalcolithic site in the lower Galilee of Israel. *Journal of Archaeological Science.* 46: 96-106.

Walker, CP. 2009. Landscape Archaeogeophysics: A Study of Magnetometer Surveys from Etowah (9BW1), the George C. Davis Site (41CE19), and the Hill Farm Site (41BW169). ProQuest Dissertations and Theses. Accessed 3/05/2017.

Witten, A. 2006 *Handbook of Geophysics and Archaeology*. London: Equinox Publishing Limited.

VITA

RACHEL M. GRAP

Education:	B.A. Anthropology, University of Georgia, Athens, GA May 2014
	M.S. Geosciences, East Tennessee State University, Johnson City, TN Expected August 2017
Professional Experience:	Graduate Assistant, East Tennessee State University, Johnson City, TN 2015-2016
	Teaching Assistant, East Tennessee State University, Johnson City, TN 2016-2017
Presentations:	Grap, Rachel M. and Ernenwein Eileen. (2017) Big Geophysics with Small Tools: Looking for the Big Picture One Step at a Time at Tel Shimron. Paper presented at the Computer Applications and Quantitative Methods in Archaeology International Conference, Atlanta, Georgia.
	Grap, Rachel M., Cornett, Reagan, Ernenwein, Eileen, and Franklin, Jay. (2017) Archaeological Geophysics and Ceramic Analysis of Rotherwood. Poster presented at CRITA 29th Annual Meeting in Nashville, Tennessee
	Grap, Rachel M., Franklin, Jay, and Ernenwein, Eileen. (2016) Geophysical Investigations and Ceramic Analysis of Rotherwood, 40SL61, Kingsport, Tennessee. Paper presented at the Cherokee Archaeological Symposium, Cherokee, North Carolina.
	Grap, Rachel M. Franklin, Jay, Ernenwein, Eileen, and Cornett, Reagan. (2016) Archaeological Geophysics and Ceramic Analysis of Rotherwood, a Mississippian Site in Northeast Tennessee. Poster session presented at the 73rd Southeastern Archaeological Conference, Athens, Georgia.
Honors and Awards:	2016 Viewer's Choice Award- ETNGIC Conference Map Gallery- "Geopolitical Service Area Analysis of Polling Locations in Washington County, TN"